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Evaluation of Asphalt Longitudinal Joint Construction and Practices in South Carolina

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EVALUATION OF ASPHALT LONGITUDINAL JOINT CONSTRUCTION AND PRACTICES IN SOUTH CAROLINA

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ABSTRACT

Joints are the weakest area of an asphalt pavement and longitudinal joint cracking occurs for a number of reasons that lead to low density, low indirect tensile strength, and high permeability at the joint. The purpose of this study was to evaluate the different joint construction used in South Carolina and perform comprehensive testing and analysis to compare the effects of multiple variables on the quality and performance of the longitudinal joints.

In South Carolina, 9 asphalt resurfacing projects were selected for sampling to make observations, conduct field testing, and cut cores from the joint and interior portion of the pavement for lab testing. The selected asphalt pavement constructions consisted of 3 different surface type mixes (surface type A, B, and C), 2 longitudinal joint construction techniques (safety edge and butt joint construction), and 1 rolling pattern (hot overlap).

Like other research studies, the performance of longitudinal joint was significantly worse than interior portions of the mat with respect to density, permeability, and/or indirect tensile strength (ITS). The compacted asphalt pavement density shared a direct and indirect relationship with ITS and permeability, respectively. The safety edge did not significantly improve the quality or performance of longitudinal joint. Through statistical analysis, surface mix type and depth of the compacted asphalt pavement were able to improve the performance of the joint.

ACKNOWLEDGMENTS

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CHAPTER ONE

INTRODUCTION

Background and Significance of Work

Plant mixed asphalt (hot mix asphalt [HMA] and warm mix asphalt [WMA]) are the mostly commonly used pavement materials in many roadway projects for a number of reasons. (McDaniel et al. 2012 and Transportation Research Board Committee 2001)

- Allow traffic to be opened quickly after constuction
- Allow traffic flow in an adjacent lane during construction
- Cost of materials is more economical compared to concrete
- Easy maintenance
- Recyclable
- Anti-skid resistance
- Absorb heat and melt snow
- More flexible to cracking

Although asphalt roads provide many benefits, paving one lane at a time creates a problem because it requires longitudinal joints between two adjacent lanes. With most construction materials, a joint is often considered the weakest link and asphalt pavements are no different. The joint is cited as the most common location of premature failure, and even the most durable asphalt pavement is susceptible to longitudinal joint cracking. Therefore, it is important to research and identify ways to improve the durability of longitudinal joints to improve the performance and service life of asphalt pavements and decrease life-cycle cost. Because of the importance of longitudinal joints, highway agencies have been actively researching methods to improve the longevity of asphalt pavements by improving the quality of joints since at the least the 1960s (Buncher et al. 2012).

When fresh, hot asphalt is placed next to a substantially cooler, compacted pavement, the resulting joint and surrounding area will typically form a weak plane that is less dense and more permeable than the interior portions of the pavement mat. This creates issues because when the permeability is high, the chance of water and air infiltrating the pavement is greater, which can accelerate the deterioration near the joint due to moisture, freeze-thaw, and oxidation. The damage from water and air can cause cracking and raveling in the beginning and allow more water and air to penetrate, leading to even greater deterioration such as joint failures and potholes (Williams 2011). Longitudinal cracking is illustrated in the photos provided in Figure 1.1.

Longitudinal joint cracking issues continue to be seen due to the limited budgets and time to complete the pavement construction before a deadline, thus potentially limiting focus on improving the quality of longitudinal joints. Therefore, it is important to pay particular attention to proper practices to construct quality, long-lasting joints to minimize the occurrence of premature joint failures. In response to these common failures, some state departments of transportation (DOT) have conducted research and developed best practice guidelines specific to the conditions in their state (Buncher et al. 2012; McDaniel et al. 2012; Kandhal et al. 1997; Williams et al. 2013). These research studies have indicated that creating quality joints requires understanding of proper joint construction techniques, appropriate methods to measure the quality of joints after construction, and specifications for the quality of constructed joints.

(a) (b) (c)

Figure 1.1: SC 93 Longitudinal joint cracking (a), (b) and (c) Pickens County, SC

Across the country and around the world, many longitudinal joint constructions techniques have been studied with varying degrees of success and even contradictory results with the same techniques. This is due to the fact that joint quality is influenced by a number of factors such as the type of mix and condition of the site, and there is no "silver bullet" solution to joint construction. Some of the reported factors that affect the quality of joints include (Buncher et al. 2012):

- Lift thickness
- Nominal maximum aggregate size (NMAS) in the asphalt mix

- Mix type
- Lane configuration
- Traffic control requirements
- Project scheduling
- Roller patterns
- Special joint tools (e.g. notched wedge joint and cutting wheel)
- Joint adhesives
- Joint sealers

Problem Statement

In an asphalt pavement, joints are considered the weakest part of the pavement as they frequently fail quicker compared to the surrounding pavement areas, resulting in the need for costly repairs. Improving the construction and compaction practices to impove the quality of the longitudinal joint could extend the life and reduce the life-cycle cost of pavements by minimizing premature failure at longitudinal joints (McDaniel et al. 2012). The awareness of the issues and the need for better quality and performance of long-lasting joints needs more attention to minimize longitudinal joint cracking problems.

Research Objectives and Scope

The goal of this study was to identify best practices for the construction of longitudinal joints in asphalt pavements in South Carolina to create a best practices guide supported by research data. To achieve this goal, an extensive literature review was conducted and surveys were administered to determine the state-of-the-practice related to longitudinal joint construction and specification. Comprehensive field and laboratory testing was also performed to compare the effects of multiple variables on the quality and performance of longitudinal joints. Furthermore, the research involved investigating opportunities for improvement of longitudinal joints and developing a document of best practices for joint construction informed by research results to improve the performance and life-cycle costs of asphalt pavements.

Organization of Thesis

This thesis consists of 6 chapters, which are an introduction, literature review, survey, research methodology, results and discussion, and conclusions and recommendations. The first chapter provides the problem statement, background, and the research objectives and scope. The second chapter contains a comprehensive literature review on the topic of longitudinal joint construction and performance. The third chapter summarizes collected survey polls and free responses. The fourth chapter explains the experimental procedures followed in this research. The fifth chapter discusses the results of the field and lab testing. Lastly, the sixth chapter provides a summary of the study and presents the conclusions and recommendations based on the findings.

CHAPTER TWO

LITERATURE REVIEW

Overview

Longitudinal joints are formed when pavement lanes are paved one lane at a time to minimize traffic disruptions by allowing traffic to flow on the other lane. When a first lane is constructed, the fresh asphalt mix is placed resulting in an unconfined edge where there is no structural support to restrain new mix from sloughing laterally during compaction. On the other hand, the second lane will have a confined edge during compaction at the joint of two lanes where the first paved lane and the new second lane meet. Therefore, two uneven surfaces can form at the joint due to the confined and unconfined edges (McDaniel et al. 2012). Regarding temperature, the edge of the first paved lane will cool down to the ambient temperature while the edge of the second lane is paved, creating bonding issues due to temperature differences. The structural support and temperature differences of the two lanes generate problems such as lower density, higher permeability, higher segregation, and lower adhesion at the joint (Estakhri et al. 2011; Williams 2011.) Zinke et al. mentioned a lack of material at the interface of the two pavement lanes is also responsible for low density at the joint (2008). These factors and others will influence the durability of hot mix asphalt (HMA) pavements. Longitudinal joints are identified as the weakest part of HMA pavements, and more problems and failures are likely to occur at the longitudinal joint than the wheel paths, edges, and other parts.

Longitudinal joint cracking can occur at a weak joint resulting from high air voids content or separations at the surface which can connect to other voids within asphalt layers to initiate deteriorations at the joints by allowing air and water to infiltrate deeper into the pavement. Once water infiltrates asphalt layers, debonding can occur due to stripping and reduce the service life of a pavement. In the colder environments of northern regions, ingress of water can cause joint failures due to freezing and thawing cycles. When air enters the asphalt pavement, it can oxidize the asphalt binder which accelerates the aging process and lowers the bond strength. Longitudinal joint cracking issues have been the focus of many research efforts and many joint construction practices have shown to be successful in improving the performance. However, many states have identified various methods as best longitudinal joint practices based on field and lab performance. Therefore, more research is needed to evaluate the practices and conditions in each state.

In the typical pavement construction process, the first lane is allowed to cool after placing a fresh mix of asphalt and compacting with rollers. Then, the second lane is laid adjacent to this lane with the same fresh mix material. When hot asphalt meets the existing cooled pavement joint, a joint is formed between the two pavements—the weak link. When placing the new asphalt for the first lane, the density at the edge of the asphalt will typically be lower than the density of the central portions of the mat because the edge is unconfined during compaction. Estakhri et al. showed there is an area of low density at the edge of the first paved lane, which was confirmed in the literature that stated the same point (2011). In this report, the first lane is referred to as the “cold lane.” When placing the fresh asphalt on the second lane, the mix may not bond properly at the joint due to the temperature difference between hot fresh asphalt and cooled asphalt of the first lane. The second lane is referred to as the “hot lane” in this report.

Rolling Patterns

Compaction at longitudinal joints is accomplished using steel drum rollers and a pneumatic roller and different rolling patterns are practiced to improve the quality of the joint. There are hot overlap, hot pinch and cold roll methods and each method specify different setting of a roller and where roller should compact during passes. Each roller pattern can affect joint performance differently.

Hot Overlap

The hot overlap method is a pattern commonly used to compact a longitudinal joint. When using the hot overlap method, the breakdown roller should be approximately 6 in (152 mm) over the cold lane while the majority of the roller is on the hot lane (Figure 2.1). The roller should also be in the vibratory mode during compaction. This is considered an efficient rolling method because the majority of roller travels on top of the hot lane. The hot overlap method helps minimize the vertical differential between lanes, and it is typically advised for achieving an adequate bond at the joints (Williams 2011; Kandhal 1997). One issue with the hot overlap method is that it may cause lateral movement of the mat (Buncher et al. 2012).

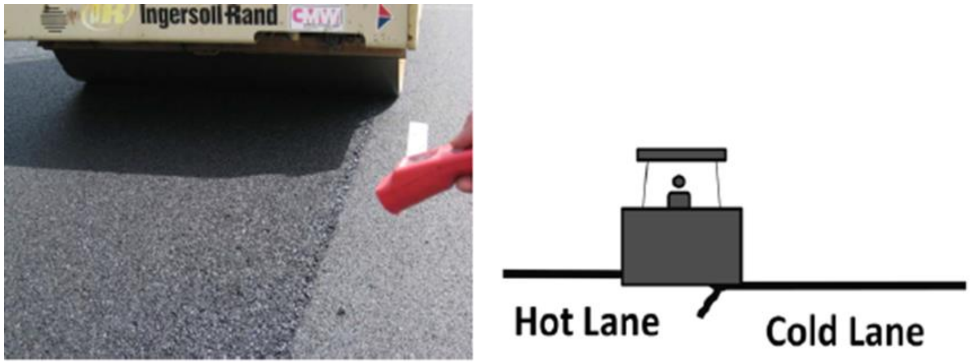

Figure 2.1: “Hot Overlap Rolling Pattern” on asphalt pavement. (Williams 2011).

Hot Pinch

The hot pinch method requires the roller to be placed 6 in (152 mm) away from the joint (Figure 2.2) and requires the roller to be in vibratory mode during compaction. By placing the roller away from the joint, the roller pushes HMA laterally towards the joint. This method is the preferred choice for tender mixes or relatively thick lifts (Kandhal 1997). It has been reported that the hot pinch method has resulted in improved joint performance (Williams 2011; Williams et al. 2013). When the hot pinch method is used, the lateral movement of the material can form a hump after the first pass. The hump needs to produce an even uniform surface and it is important to note that potential exists for cracks to develop along the pinch lines. After the hot pinch method, it is recommended to use a pneumatic tire roller instead of steel roller to compact joints because this type of roller allows to knead low density areas while steel roller only provides little or no compaction (Williams 2011) due to bridging effects. Other research suggested using the hot overlap method when there are signs of cracking when using the hot pinch method (Buncher et al. 2012).

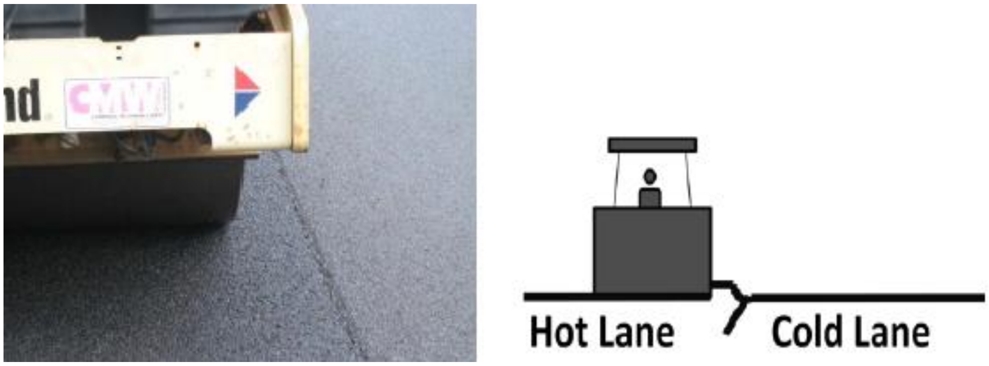

Figure 2.2: “Hot Pinch Rolling Pattern” on asphalt pavement. (Williams 2011).

Cold Roll

The cold roll method requires the roller’s majority contact surface to be on the cold lane instead of the hot lane (Figure 2.3). The roller overlaps the hot lane by 6 to 12 in (152 to 304 mm). The roller is set in a static mode during compaction to avoid the development of cracks on the cold lane. This method is known for eliminating vertical differential at the joint, but it is also considered to be inefficient because it requires compacting areas that are already compacted. The static mode is used for the cold roll to avoid damaging the cold lane and it is less efficient than the vibratory mode. Additionally, when the roller is compacting from a cold mat area, the remainder of the hot mat cools, making it more difficult to compact the remainder hot lane in successive passes. However, some studies have reported that the cold roll method could minimize potential developments of cracks at longitudinal joints (Marquis 2001). When compacting the free edge of the cold lane, Williams et al. recommended not using a pneumatic tire roller because it can cause transverse movement and push the material away from the edge. Therefore, he recommended only to use steel-wheel rollers to compact even though the cold lane may show signs of cracks at the free edge.

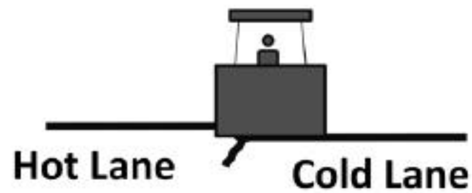

Figure 2.3: “Cold Roll Rolling Pattern” on asphalt pavement. (Williams 2011).

Longitudinal Joint Construction Technique

The quality of longitudinal joints can be improved by employing different longitudinal joint construction techniques. These include are echelon paving, sequential mill and fill, wedge, edge restraint, joint maker, cutting wheel, infrared joint heater, and, joint adhesive and sealant methods. Some of these techniques involve attaching special mechanical device to a paver, a roller, or a small motorized vehicle. The other techniques involve increasing number of heavy machineries, changing the order of pavement construction, and applying chemical products. Each construction technique has different affect on the performance of the joint and shoud be reviwed.

Echelon Paving

Echelon paving involves paving multiple lanes at the same time using at least two pavers, and it minimizes longitudinal joint' issues by placing two or more adjacent lanes at the same temperature. The second paver remains close behind the first paver to ensure the temperature at the joint is hot. Case studies in Canada showed excellent longitudinal joint quality using the echelon paving method that eliminated the need for joint maintenance (Uzarowski 2009). Although this method saves time compared to constructing one lane at a time, it is not considered a practical option because of the disruption of the traffic flow and requires multiple pavers and trucks, which may also increase the operation cost.

Sequential Mill and Fill

When typical mill and fill occurs, the pre-existing pavement is milled prior to placing a new surface and all lanes are typically milled together. With sequential mill and fill, only one lane milled at a time instead of milling both lanes. Then, the milled surface and confining edges are thoroughly cleaned before a paver fill the milled pavement area with fresh asphalt mix followed by compaction. This method provides the confining edge of the cold lane(s) for the hot lane, which results in increased pavement density (Williams et al. 2013). This also eliminates common uneven surface issues at the longitudinal joint. This method does not require any specific equipment like other methods described in the following sections.

Wedge Construction

When constructing longitudinal joints, a paver screed with a special plate or a kicker plate is used to shape free edges of the cold lane, forming a shoe or boot shaped edge (Figure 2.4). Wedge construction can be done with and without a notch at the top of the edge. Mallick reported that without the notch, the aggregate in the overlapping wedge cannot withstand the loads of rollers and compaction could crush the aggregate without the extra space (2007). The crushed aggregate could cause raveling problems along longitudinal joints. To compact the wedge, a special side roller must be attached to the compactor and different degrees of graduated surfaces, such as 3:1, 6:1, and 12:1 slope, are formed. The shape of the edge helps reduce transverse movement during the joint compaction. When the face of the graduated surface meets the overlapping material from the hot lane, the heat also provides better aggregate interlock during the joint compaction. Buncher et al. reported that other agencies found that the notched wedge joints provide higher densities than vertical or butt joints and the same results were seen in Nener-Plante's research as well (2012; 2012).

Figure 2.4: Schematic drawing of notched wedge joint construction

Edge Restraint

During the compaction of an asphalt pavement, a compaction drum with an additional fixture is used to provide confined edges or structural supports on the unconfined side of the mat (Figure 2.5). The difference between the wedge construction and the edge restraint methods is that with the edge restraint method, the pavement layer edges are more vertical than the wedge construction method. A hydraulically powered wheel attached to a roller will prevent horizontal movement of materials during the compaction and allow higher density measurements at the joint due to the specific compaction. This method relies on having an experienced operator and the results may be inconsistent. (Williams 2012)

Figure 2.5: Edge restraint construction (Fleckstein et al. 2002)

Joint Maker

The joint maker allows the contractor to pre-compact the mix ahead of the screed by attaching a rounded-edge metal mass to the side of a paver screed. Also, a kick plate is attached to the end of paver screed to push extra asphalt mixture to the joint (Figure 2.6).

This method provides an adequate amount of asphalt material at the joint to meet the appropriate thickness and density. It can also be added into notched wedge joint technique.

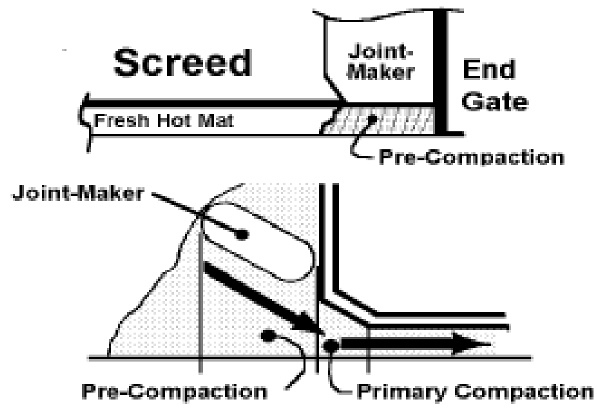

Figure 2.6: Joint maker construction (Fleckstein et al. 2002)

Cutting Wheel

The cutting wheel method involves cutting portions of the unconfined edge of the pavement with a 10 in (254 mm) diameter cutting wheel after placing a new lane. The cutting wheel is attached to an intermediate roller or other motorized equipment to cut and remove the low density materials at the edge of the cold lane (Figure 2.7). When the outer portion of the free edge is removed, the new, clean edges will have a higher density and provide better confining support to the adjacent pavement lane that will follow. This method's performance is dependent on the skills of the roller operator because it depends on how well the operator can cut straight lines.

Figure 2.7: Cutting wheel construction (Buncher et al. 2012)

Infrared Joint Heater

The joint heater is mainly used on the joint before paving the hot lane to preheat the cold edge to lessen the temperature differential and improve the adhesion between the hot and cold lanes. The infrared joint heating method has been compared to the echelon method because those are only two methods that minimize temperature differences. Increasing the temperature of the existing HMA material helps to improve bonding between hot and cold lanes, and reduce the viscosity, or increase the flowability (or compactability) of material. When bonding and compactability are improved, an increase in the density at the joint can be expected.

The infrared heater is operated using a propane fired heater and can be pulled behind a small motorized tractor on a trailer or mounted on a truck (Figure 2.8). If needed, another heater can be attached to a paver to meet the desired compaction temperature. It is essential to monitor the compaction temperature or moving speed because previous studies reported that scorching effects were seen on pavements due to exposure to high temperature. The infrared heater is known as the most effective construction method to mitigate longitudinal joint cracking by increasing the compaction of the joint. The use of a joint heater decreases permeability, increases density, and increases the indirect tensile strength of the longitudinal joint (Huang and Shu 2010; Williams 2011; Williams et al. 2013).

The efficiency of the infrared heater may decrease when the thickness of the lift is increased, because infrared may not be able to penetrate to the bottom of the layer at the desired temperature without scorching the top layer. Daniel stated the infrared heating was capable of penetrating and heating up the mixture within 25 to 50 mm (1 to 2 in) of the joint up to around 60˚C (140˚F) during the initial compaction (2006). Since there have been mixed opinions and results in the past, more studies need to be conducted on the infrared joint heater method.

Figure 2.8: Infrared joint heater construction (Nener-Pante 2012)

Joint Adhesives and Sealants

Adhesives and sealants are used to prevent the ingress of water and air by bonding the joint or sealing the surfaces of layers to minimize the damage that can occur at longitudinal joints and to preserve high quality joints. The adhesives and sealants are supposed to reduce the permeability, but the majority of studies reported that there were no changes in permeability when using these products. Huang and Shu explained that sealers are not strong enough to withstand the falling head permeability test and emphasized that the absorption test is more appropriate to see the effectiveness of joint adhesives and sealants (2010). Commonly, adhesives are applied during and sealants are applied after joint construction. The adhesive is applied on the cold lane face of the joint before the hot lane is paved (Figure 2.9). The adhesive can also be applied to the joint after both sides of lanes are compacted, or it can be applied to the underlying layer before placing the overlay. When adhesives are placed beneath the overlay, the heat transferred from the HMA mixture is expected to cause the product to migrate upward through the joint, theoretically reducing interconnected voids (Williams, 2011). The sealants are applied to only top of the joint after compaction.

Figure 2.9: Joint adhesive and sealant construction (Williams 2011)

Specification

Many states have specifications on mat density requirements for HMA layers, but many do not have any specifications or guidelines for constructing longitudinal joints. Highway agencies have been conducting research on longitudinal joint construction since the 1960s and have found multiple longitudinal joint construction methods and compacting patterns that provide superior performance. However, there have not been any significant improvements on longitudinal joints and most states do not have specifications or guidelines for the joint construction or quality. Figure 2.10 identifies 16 states that have set specifications on longitudinal joints according to McDaniel et al. (2012), Wang et al. (2016), and Williams (2011) and Table 2.1 lists the state requirements for the constructed joints. Buncher et al. reported that 17 states had a minimum density requirement at the joint and 35 states had some sort of longitudinal joint specification (2012). The minimum density requirement ranged from 89% to 92% of theoretical maximum density according to surveys.

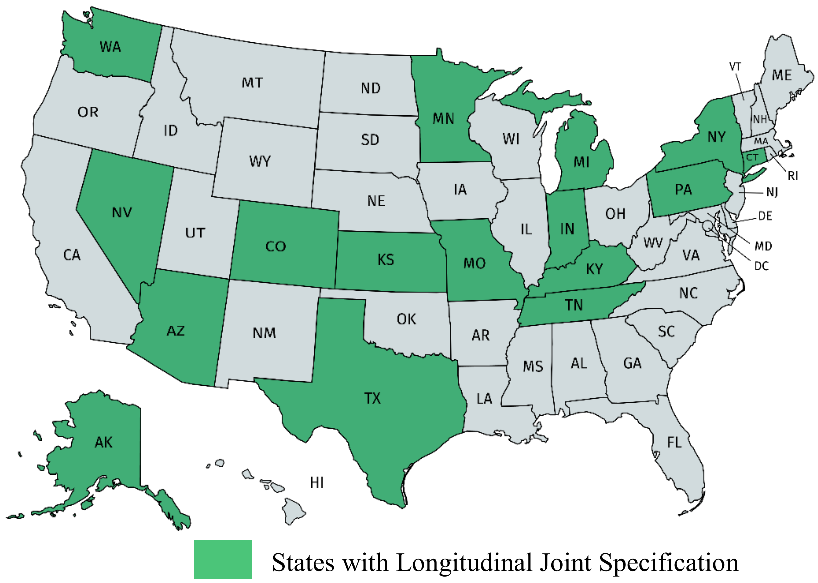

Figure 2.10: States with specifications for longitudinal joint density in 2011-2012

(McDaniel et al. 2012; Williams 2011)

Table 2.1: States with specifications on longitudinal joint density (McDaniel et al. 2012; Wang et al. 2016; Williams 2011;)

JOINT DENSITY REQUIREMENT		
State	***Percent***	***Requirement***
AK	> 91	of theoretical maximum specific gravity (2011) (2016)
AZ	-	same density requirements as mainline paving (2016)
CO	≥ 92	of theoretical maximum specific gravity (2011), tolerance 4% variation (2016)
CT	90-97	of theoretical void free density (2011)
IN	> 91	of theoretical maximum specific gravity (2012)
KS	≥ 90	of theoretical maximum specific gravity, or interior density minus joint density less than equal to 3 lb/cu.ft. (2015)
KY	87-97	of theoretical maximum specific gravity (2016)
MD	-	method specification for longitudinal joints (2012)
MN	-	same density requirements as mainline paving (2011)
MI	≥ 89	of theoretical maximum specific gravity (2012) (2016)
MO	> 98	of the interior density (2011)
NV	≥ 90	of theoretical maximum specific gravity (2016)
NY	90-97	of theoretical maximum specific gravity (2016)
	90	of theoretical maximum specific gravity (2011)
PA	90	of theoretical maximum specific gravity (2012)
TN	89	of theoretical maximum specific gravity (2011)
TX	> 90	of theoretical maximum specific gravity (2011) and no more than 3% less than mat density (2012) (2016)
WA	> 90	of theoretical maximum specific gravity (2012)
FAA	93.3	of theoretical maximum specific gravity (2011)

Offset Requirement

When constructing asphalt pavement, joint is formed and joint of each asphalt layer is stacked and typically spaced 6 in as shown in Figure 2.11. The offset is supposed to prevent continuous water intrusion by disconnecting direct paths of two joints between surfaces and underlying courses. Out of 50 states, 24 states have offset requirements between 2 and 12 in for longitudinal joints of successive layers. Some states even require the surface joint to be offset from the lane lines by 6 to 12 in separately and yet other states require the joint at the surface to be located on the lane line (McDaniel 2012; Williams 2011). The states with an offset requirement is shown in Figure 2.12.

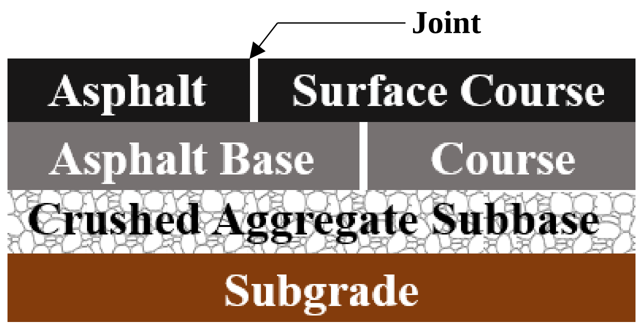

Figure 2.11: Longitudinal joints offset

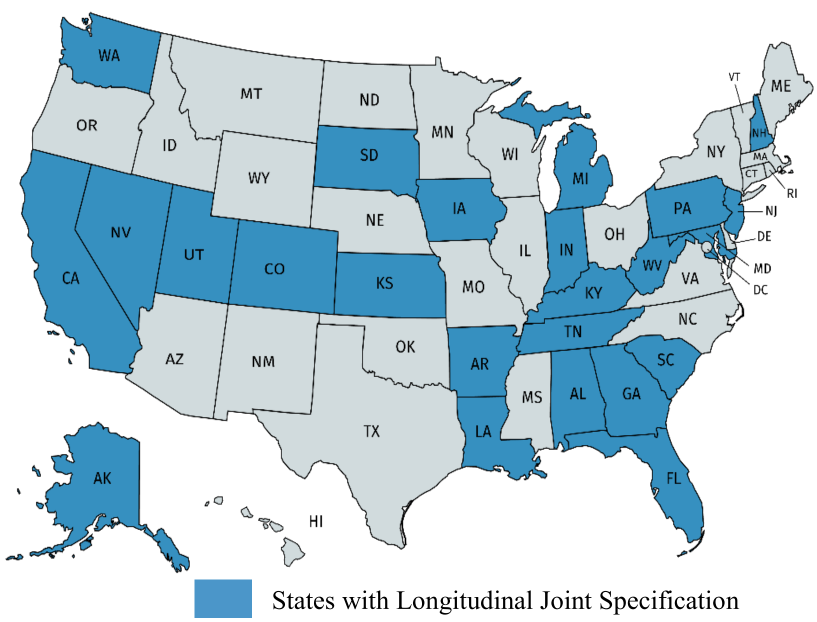

Figure 2.12: States with offset specifications for longitudinal joints in 2011-2012 (McDaniel et al. 2012; Williams 2011)

Compaction Requirement

In terms of compaction, 9 states specifically mentioned the first roll must be done on longitudinal joints to maximize the compaction. Additionally, some states had specified compaction methods depending on certain conditions (McDaniel 2012; Williams 2011). The states with compaction requirement is shown in Figure 2.13.

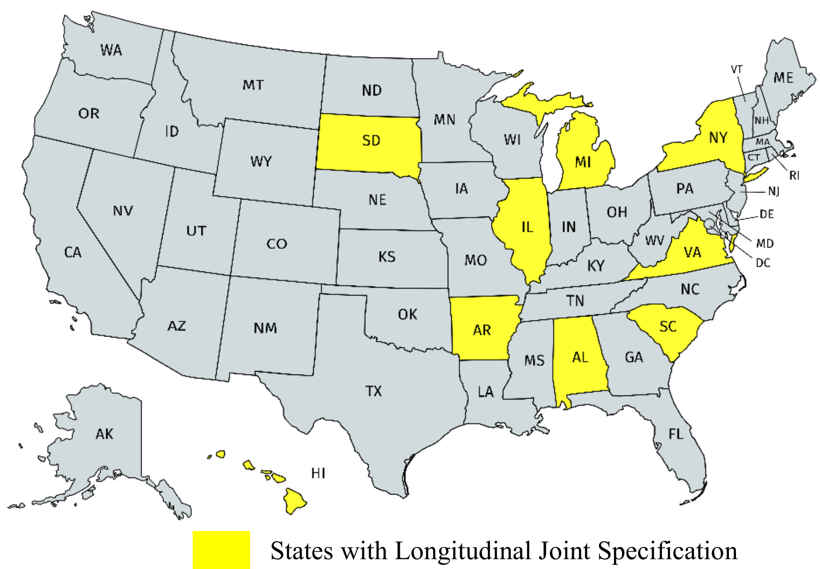

Figure 2.13: States with compaction specifications for longitudinal joints in 2011-2012 (McDaniel et al. 2012; Williams 2011)

Tack Coat Requirement

The tack coat is bituminous liquid asphalt that promotes bonding among particles and layers, 16 states specify that tack coat must be applied on the face of the longitudinal joint or on the surface of the joint (McDaniel 2012; Williams 2011). The states with tack coat requirement is shown in Figure 2.13.

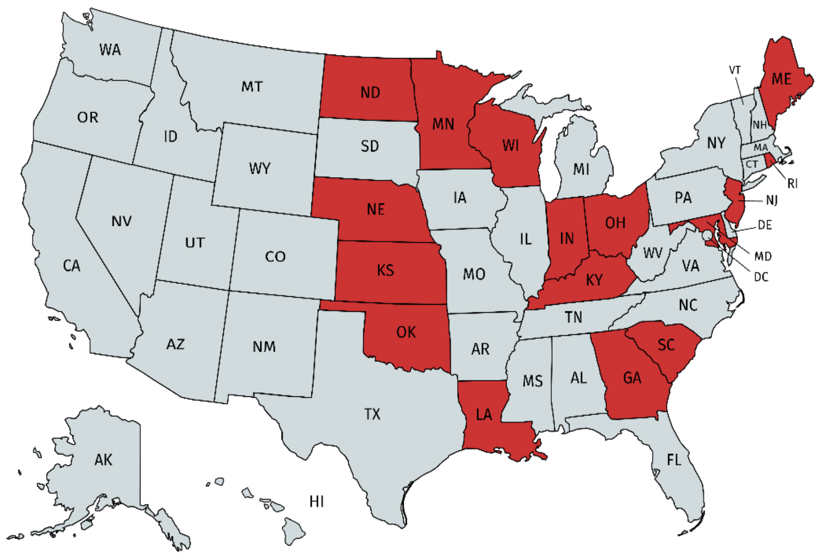

Figure 2.14: States with tack coat specifications for longitudinal joints in 2011-2012 (McDaniel et al. 2012; Williams 2011)

Mix Design

Asphalt mix is typically composed of aggregate, binder, and sometimes other additives and changes in the properties or quantity of each component can influence the quality and performance of a longitudinal joint. Cooley et al. stated that the nominal maximum aggregate size (NMAS) can influence permeability of a pavement and confirmed that asphalt mixtures with large NMAS aggregate require a dense and thick lift for the asphalt pavement to become impermeable (2002). In accordance with Cooley et al. and Buncher et al. recommended that the thickness of the asphalt pavement layer should be at least 4 times the nominal maximum aggregate size (NMAS) of coarse aggregates and 3 times the NMAS of fine aggregates (2012). Moreover, based on the survey results and literature reivews, Buncher et al. and Mallick et al. suggest using the smallest NMAS mix which will minimize a rutting issue because the smaller NMAS mix is less permeable than the large NMAS mix. To make the surface less permeable, it is recommended to use a finer gradation and add more binder to the mix to lower the air voids in the mix (2012, 1999).

Other States and Organizations Findings

Michigan, Wisconsin, Colorado, and Pennsylvania (Kandhal et al. 1997)

Performance of longitudinal joints constructed using different methods were observed across Michigan, Wisconsin, Colorado, and Pennsylvania after a couple years of service and researchers reported that the notched wedge joint technique of 12.5 mm vertical offset with a 12:1 taper had the best performance based on visual inspections and density measurements. The cutting wheel and the edge restraining methods had high density measurement, but the report did not recommend these two methods because they rely on the skills of the operator. The report stated that the hot overlap method is the best rolling technique and hot pinch method as the second optimal option. The construction and rolling techniques conducted included hot overlap, hot pinch, cold roll, 12:1 wedge, edge restraining, cutting wheel, joint maker, 3:1 wedge, 3:1 wedge with infrared heating, and rubberized asphalt tack coat.

Tennessee (Huang et al. 2010)

Research by Huang et al. focused on comparing and evaluating the effectiveness of different joint adhesives (Crafco, Pavon, polymer emulsion, and basic emulsion) and joint sealers (Joint bound and Replay), and the effectiveness of an infrared joint heater itself. In categories of adhesives and joint sealers, the polymer emulsion and basic emulsion resulted in the lowest air voids and permeability and revealed that only the polymer emulsion had an increase in indirect tensile strength (ITS) of the longitudinal joint. Among all construction practices evaluated in this research, the infrared heated longitudinal joint performed the best in terms of air voids, permeability, and ITS.

Arkansas (Williams 2011)

Arkansas highways constructed using different longitudinal joint techniques revealed the joint heater, notched wedge, and joint sealer methods were most successful, and the joint heater method recorded the highest density measurements. On the other hand, the pavements with joint adhesive and the tack coat measured the lowest density measurements. When the permeability, absorption, and infiltration levels of joints were compared with the density, results showed that highly dense asphalt pavements had low permeability, absorption, and infiltration levels while low density asphalt pavements had opposite results. The joint stabilizer was the most effective in water related testing followed by the joint heater and notched wedge methods. For the rolling methods, authors recommended the use of the hot pinch and cold roll methods.

Maine (Nener-Pante 2012)

Nener-Pante conducted a field study in Maine to evaluate vertical edge joints, notch wedge joints, and notch wedge with infrared heated joints and reported most of the joint density was above 90% of the maximum specific gravity, which is uncommon, for all three joint construction methods. Among the three construction practices, the vertical edge had the lowest density recordings. The notch wedge joints exhibited some improvements in density compared to the vertical edge joints, but the density difference between the vertical edge and heated notch wedge joints was not significant.

Canada (Uzarowski et al. 2009)

Uzarowski et al. evaluated echelon paving with and without a materials transfer vehicle and the joint heating method in parts of Canada. The three cases showed successful results in field density by raising the joint temperature. Additionally, the author conducted a study of improving the quality of longitudinal joints using a warm mix asphalt (WMA), but concluded more studies need to be conducted to evaluate the effectiveness of WMA.

Canada-Ontario (Marks 2006)

Four longitudinal joint techniques (butt joint, joint heater, joint maker, and combination of joint heater and joint maker) were evaluated and the joint quality was compared using density. From this study, no single method was found to be superior and all joint densities were excellent throughout the project.

Kentucky (Fleckstein et al. 2002)

Research in Kentucky reported improvements in density not only at the joint but also across the mat when the notched wedge method was used. The author explained the wedge was restraining the edge of the mat and decreasing the lateral movement of the mat concurrently. The notched wedge joints also produced the lowest permeability of all joint construction methods. The notched wedge was recommended to be used only on 1.5 in thick lift or thicker. For the restrained edge method, improvements in density and permeability at the joints were seen compared to the control sections. One problem with using the restrained edge method was creating a longitudinal ridge in the mat when the wheel was compacting at the edge of the pavement. The infrared joint heater was the most successful in increasing density and moderately decreasing the permeability, but authors emphasized the importance of the need for a better attachment that does not impede the speed of the paving train. The study also evaluated joints constructed using Crafco and Tbond joint adhesives in the field, and both reduced the permeability of joints. The restrained edge method had the highest average normalized density, and the notched wedge had the second highest density at joints. Among all the joint construction methods, the joint maker did not statistically improve density at any area and was not recommended for longitudinal joints.

Virginia (Appea et al. 2010)

The Virginia Department of Transportation and Virginia Asphalt Association cooperated to develop a communication and training program focused on proper joint compaction instead of developing a longitudinal joint density specification and/or requiring specific construction techniques. Improvements in joint density were observed continually in the surface mix with 12.5 mm and 9.5 mm nominal aggregate size after the adherence of the joint memorandum. The improving trends were confirmed through statistical analysis.

Mississippi (Johnson 2000)

The research division of the Mississippi Department of Transportation evaluated the effectiveness of a joint maker and pre-compaction screed in achieving higher and more uniform density across the HMA pavement mat and the longitudinal edges. The research included a field study and found increases in density measurements up to 2% along joints and across the mat. However, the author pointed that out the control sections provided a more uniform density and lower standard deviation when compared to the joint maker and pre-compaction screed sections.

FAA Federal Aviation (Kandhal et al. 2007)

Longitudinal joint cracking is not only seen on highways, but also in asphalt airfields. A study sponsored by the FAA determined that using a combination of notched wedge joint and rubberized asphalt tack coat was the most preferred choice if echelon paving is not practical. The second and third most preferred joint construction methods were rubberized asphalt tack coat and notched wedge joint, respectively. The study made recommendations on asphalt airfield longitudinal joints based only on literature reviews, surveys, and recommendations from airport engineers and consultants.

Connecticut (Zinke et al. 2008)

The Connecticut Department of Transportation and the Federal Highway Administration investigated the performance of notched wedge joint compared with a traditional butt joint at various random locations in Connecticut. From this research project, Zinke et al. identified there were lower average density recorded 6 in on the cold side of the joint compared to those 6 in on the hot side of joint. To address the issue, the notched wedge joint method was used to reach a higher average density, compared to butt joint construction 6 in on the cold side of the joint and at the joint. The authors reported the use of the notched wedge joint did not impede the paving process.

Wisconsin (Toepel et al. 2003)

In previous studies conducted at the National Center for Asphalt Technology (NCAT), wedge construction was not favorable due to inferior performance in Wisconsin, but it performed better than conventional methods in Michigan. It was noted that the Wisconsin wedge did not have the ½ in vertical notch like the Michigan wedge and the face of Wisconsin wedge was not compacted. Therefore, further study was conducted to investigate the effectiveness of wedge construction with different compaction in Wisconsin. NCAT evaluated 8 joint construction techniques, including butt joint, wedge joint with truck tire rolling, wedge joint without rolling, wedge joint with steel side roller, wedge joint with rubber side roller, edge joint with tag-along roller, cutting wheel, and edge constraint methods. Among these construction techniques, the wedge joint with steel side roller and the wedge joint with the tag-along roller were the best performers when comparing density at the joint.

Nevada (Sebaaly et al. 2008)

A study was completed in Nevada to obtain knowledge and aid in the development of a longitudinal joint specification. The study consisted of 5 construction practices and 2 rolling patterns. The 5 joint construction methods included, natural slope, edge restraining, cutting wheel with and without a rubberized tack coat, and 3:1 tapered wedge. The rolling patterns studied included, hot overlap and hot pinch methods. When the performance of rolling methods was compared, they were similar statistically. Out of the 5 joint construction methods, edge restraining, cutting wheel with tack coat, and 3:1 tapered wedge were recommended.

Indiana (McDaniel et al. 2012)

For the Indiana Department of Transportation, McDaniel listed advantages, disadvantages, and comments on past performance and quality of longitudinal joint construction methods in Table 2.2.

Table 2.2 Joint construction techniques' advantages and disadvantages (McDaniel et al. 2012).

Joint Treatment	**Advantages**	**Disadvantages**	**Likelihood of Success & Acceptance; Recommendation**
Full Width, Echelon or Tandem Paving	Avoids cold joint Good performance	Only tandem can be done under traffic Traffic control/safety issues with tandem Echelon and tandem require two pavers and two crews, which increases cost Need high capacity plant	Work well when feasible, but rarely feasible mainly because of traffic Implement when possible, but will not be routine
Various Rolling Patterns (number and type of rollers, number and location of passes, timing of passes)	Can change easily when conditions change (temperature, mix behavior, etc.) Usually does not require additional equipment or manpower	Since there is not one rolling pattern that works in all cases, experience or some tested property is needed to determine what works best in a given situation	Changing rolling patterns is easy Little to no impact on cost Maintain the lack of restrictions for certain mixes
Butt Joint	Common and familiar Can work well when properly constructed	Edge drop off requires pulling up adjacent lane (productivity impacts) Water can penetrate roadway easily if joint separates, especially if joints in underlying layers are not offset	Could work well with attention to detail but experience shows that attention is sometimes lacking Continue to require joint adhesive and fog seal

Table 2.2 (continued). Joint Construction Techniques and Issues (McDaniel et al. 2012)

Joint Treatment	**Advantages**	**Disadvantages**	**Likelihood of Success & Acceptance; Recommendation**
Tapered or Notched Wedge Joint	Avoid issue with edge drop off Can perform well if properly constructed Similar to safety edge, which is becoming more familiar and may provide confinement at the edge of lane	Requires compaction of the wedge Notch and taper dimensions need to be appropriate for NMAS and layer thickness	Can be effective Not attractive to contractors if there is a requirement to pull up adjacent lane Consider requiring compaction (preferably with vibratory plate attached to paver) for wedge
Edge Restraining or Precompaction Devices	Can increase density near joint	Requires skillful operator	Mixed performance at best Not worth promoting
Cutting Wheel	Removes low density material	‘‘Wastes’’ new mix Requires equipment and manpower to cut and to remove debris Requires skillful operator	Mixed performance at best Not worth promoting
Sequential Mill and Fill	Removes low density material from unsupported edge at center of lane Does not require new/more equipment	May require milling sub to stay on job longer or return later ‘‘Wastes’’ new mix Milling action might damage adjacent mix in place	Expert opinions are mixed Maintain contractor option Evaluate existing sequential mill and fill projects to decide whether to encourage or restrict in future

Table 2.2 (continued). Joint Construction Techniques and Issues (McDaniel et al. 2012)

Joint Treatment	**Advantages**	**Disadvantages**	**Likelihood of Success & Acceptance; Recommendation**
Infrared Joint Heater	Avoids cold joint Increases adhesion at interface Works well in some places	Requires extra equipment and fuel Lengthens paving train Interfere with delivery trucks and paving crew Safety issues Can scorch mix	Mixed performance Not worth pursuing
Joint Adhesives	Improve adhesion at the interface No negative impacts on performance Insurance against poor performance	Increase costs Require equipment and manpower Have not always demonstrated improvement in performance (permeability)	Cost increases are expected to be low when used routinely; increased performance can easily offset increase in costs Continue to require Monitor performance to support future decisions
Joint Sealer	Reduce permeability around the joint No additional equipment required No negative impacts on performance Insurance against poor performance	Increase costs Have not always demonstrated improvement in performance (permeability) Must be applied before pavement markings and after coring	Cost increases are expected to be low when used routinely; increased performance can easily offset increase in costs Continue to require Monitor performance to support future decisions

CHAPTER THREE

SURVEY

South Carolina Construction Survey

A survey was distributed to SCDOT and contractor personnel across South Carolina to gain an understanding of longitudinal joint construction practices currently used throughout the state. The study was used to elicit their opinions about some other practices and to create longitudinal joint construction guidelines. The survey was administered using Survey Monkey and was sent to construction engineers, maintenance engineers, asphalt managers, material engineers, and asphalt material managers from all 7 districts within the SCDOT (Figure 3.1). Additionally, the survey was sent to the contractor members of the South Carolina Asphalt Pavement Association (SCAPA). The survey was sent to quality control managers, asphalt plant managers, and asphalt operation managers from multiple construction companies. The survey consisted of 17 questions that are presented in Appendix A.

Figure 3.1. Map of the SCDOT engineering district boundaries.

Survey Results and Analysis

A Survey Monkey survey regarding longitudinal joint constructions was set up to collect information across South Carolina, and there was a total of 5 responses from contractors and 35 responses from SCDOT peronnel from different districts of South Carolina. Two of the 40 participants had at least 3 years of experience but less than 5 years. Ten of the 40 participants have been involved with asphalt pavement construction for at least 5 years but less than 10 years and other 28 participants had experience with asphalt pavement construction for 10 years or more (Figure 3.2). The general occupation classification of the participants can be seen in Figure 3.3. The majority of respondents were construction engineers from SCDOT.

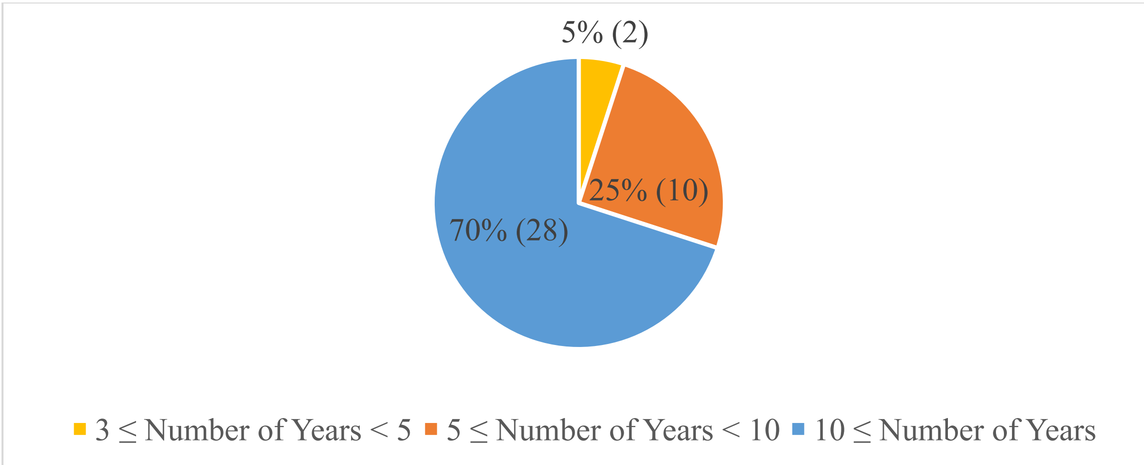

Figure 3.2: Number of years of experience (contractors and SCDOT personnel)

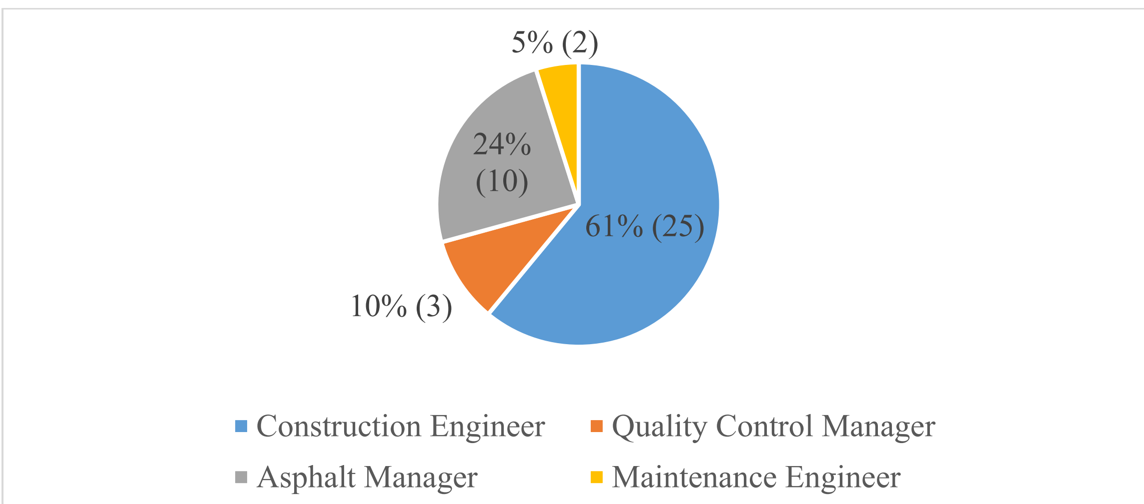

Figure 3.3: Occupation of the survey participants (contractors and SCDOT personnel)

Across South Carolina, different rolling patterns are used to construct longitudinal joints to meet South Carolina specfications on density and smoothness of the pavement mat. To understand the common practices of joint compaction that are practiced in South Carolina, the suvey asked what rolling methods are practiced or observed for the first pass (Figure 3.4), second pass (Figure 3.5), and third pass (Figure 3.6). Based on the survey responses, the hot overlap and the hot pinch methods are most commonly used for the first pass, but the use of the hot pinch method gradually decreases for the second and third pass. In constrast to the hot pinch method, the use of the cold roll method was the lowest for the first pass, but a gradual increase in the use for the second and third pass was observed.

Based on the observations of the experienced personnel, most participants responded that the hot pinch was the best rolling method to compact longitudinal joints based on visual, density, or permeability observations as shown in Figure 3.7.

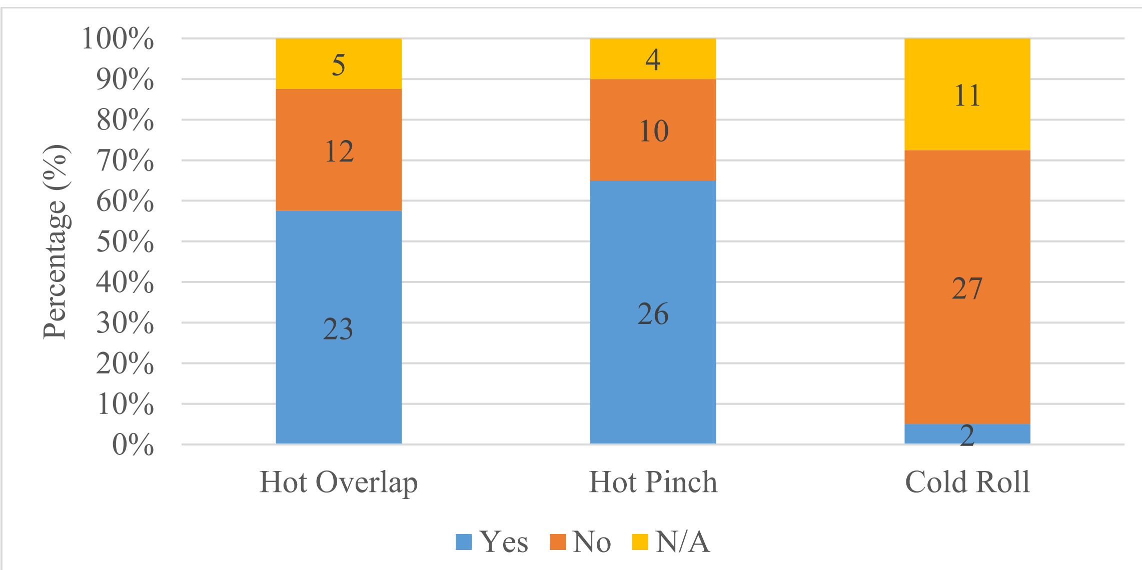

Figure 3.4: Survey of first pass compaction observed

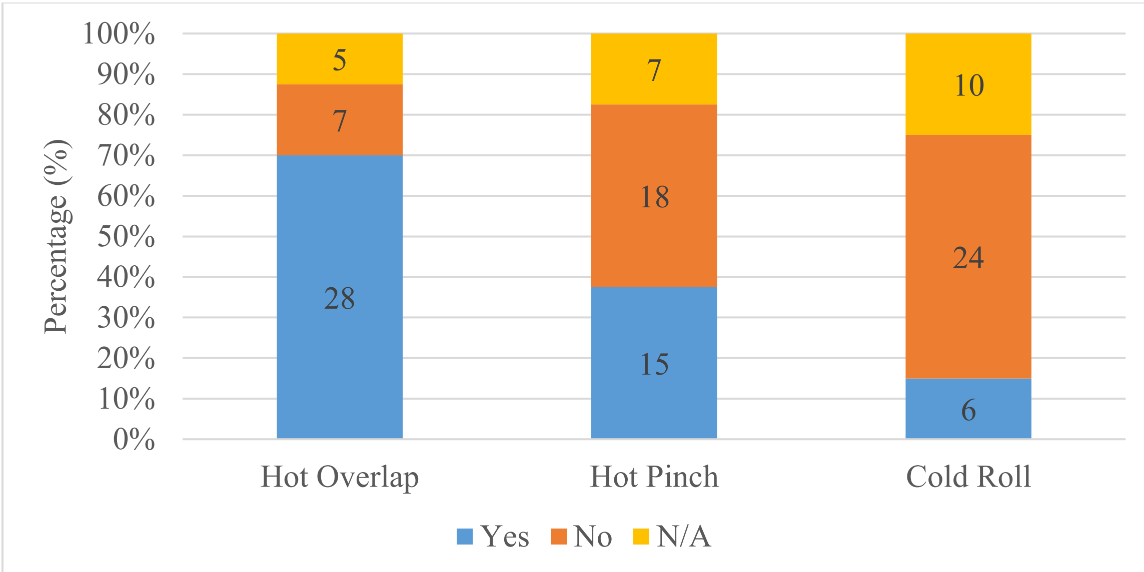

Figure 3.5: Survey of second pass compaction observed

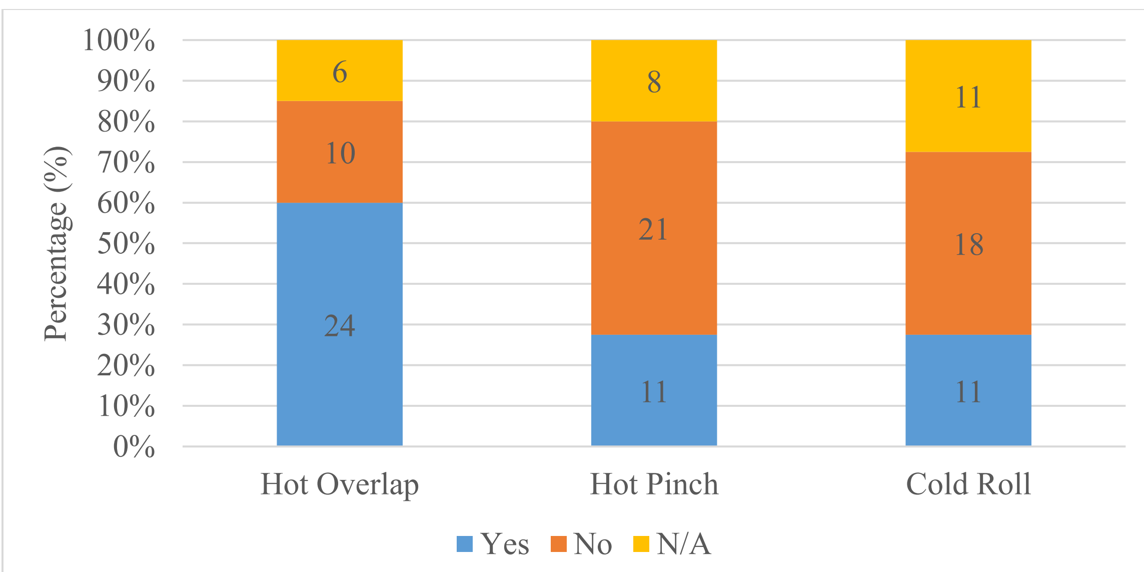

Figure 3.6: Survey of third pass compaction observed

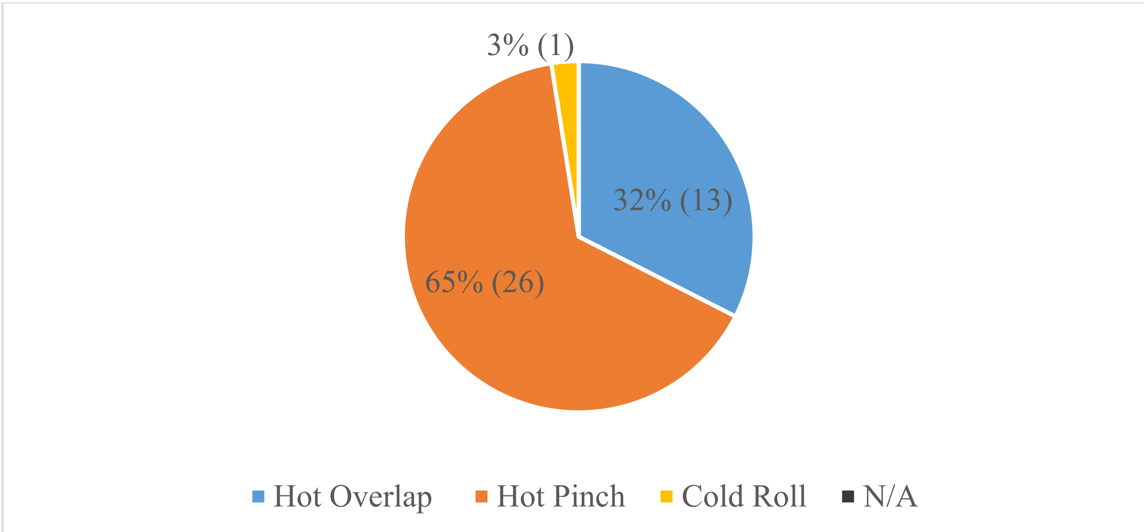

Figure 3.7: Survey of best rolling method

When survey takers were asked if there were any obstacles to using the specific joint compaction method that they consider to be the best, 2 of the contractors replied that traffic is an issue and explained that the narrow road becomes dangerous for their employees. One respondent also mentioned that it is difficult to perform the hot pinch method for night work because of roller operator's limited visibility. The other contractors responded that lane configuration presented a challenge (1 response) as well as crew management (1 response).

Five SCDOT personnel responded that the traffic of the location and the spacing concerning the safety of employees discouraged using a specific construction practice. Two SCDOT respondents noted there is difficulty in managing roller operators to correctly to follow the instructions. Two SCDOT personnel responded that there were no obstructions to performing the best construction method. Other responses included mix type (1 response), contractor buy-in (1 response), and historic preservation areas (1 response). The rest of the responses were either not related to the question or the respondents skipped the question.

A question regarding methods employed to maintain straight joint lines during asphalt pavement construction was also included and the responses are summarized in Figure 3.8. The majority stated paint or chalk marking and string lines are used to keep the joint straight.

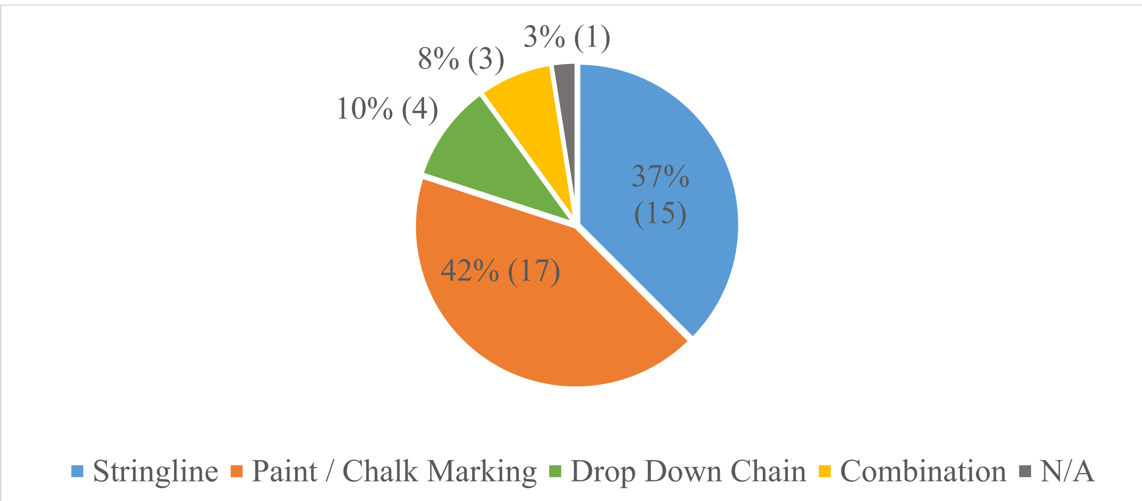

Figure 3.8: Survey of methods for maintaining straight joint lines

During the construction of asphalt pavements, the thickness and the width of the pavement mat can be adjusted based on the existing conditions of the site. When matching the edge of existing lane with the fresh asphalt mix, some of the excessive mix will become loose near the joint before compaction. The survey takers were asked what observations were made when addressing excess overlap material, and the responses are presented in Figure 3.9. Most participants stated raking or luting is done to push the excess materials back to the joint and 4 people responded that nothing is done. One person selected “other” option and stated that the excess material was placed back on the mat.

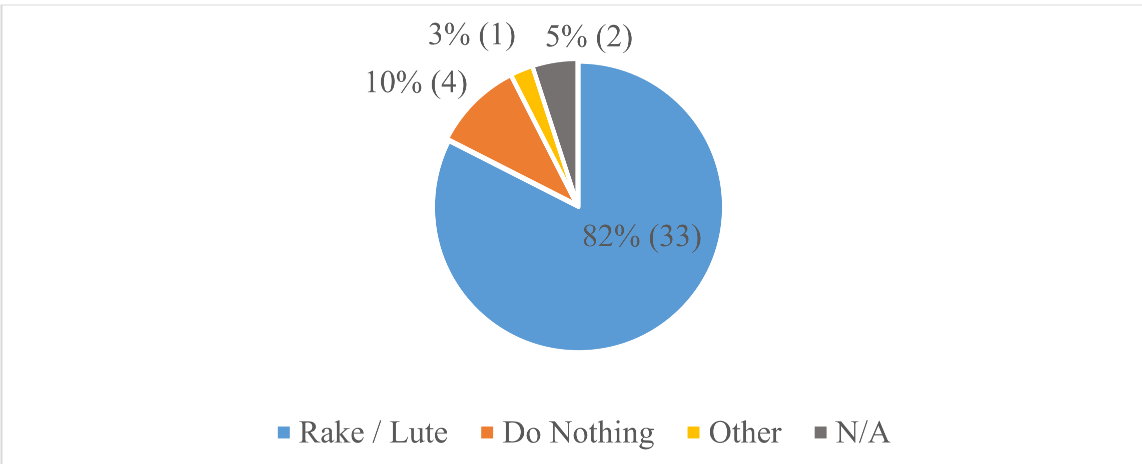

Figure 3.9: Survey of handling excess overlap material

The quality of longitudinal joints can be improved by performing different longitudinal joint construction techniques and the survey takers’ preference of all known techniques is presented in Figure 3.10. The butt joint was the most preferred technique and the joint heater is a technique that is never preferred.

The participants were asked if there were reasons why some of the construction practices are most preferred. Two contractors responded that best joint performance was the reason and 1 contractor indicated cost and ease of construction.

The most common SCDOT responses were familiarity, experience, and ease of use (9 responses). Six responses from SCDOT revealed that the preferred techniques were due to best joint performance, practical, and effective results. Moreover, 3 added that a certain technique is limited due to the traffic control and 2 mentioned increase in cost and contractors do not favor special equipment needed to pave. One responded that there are mixed opinions or proof that other methods are better than the traditional method. One participant answered that the the preferred option depended on South Carolina specifications. Only 1 respondent mentioned some of the practices cause a variation of temperature across a mat.

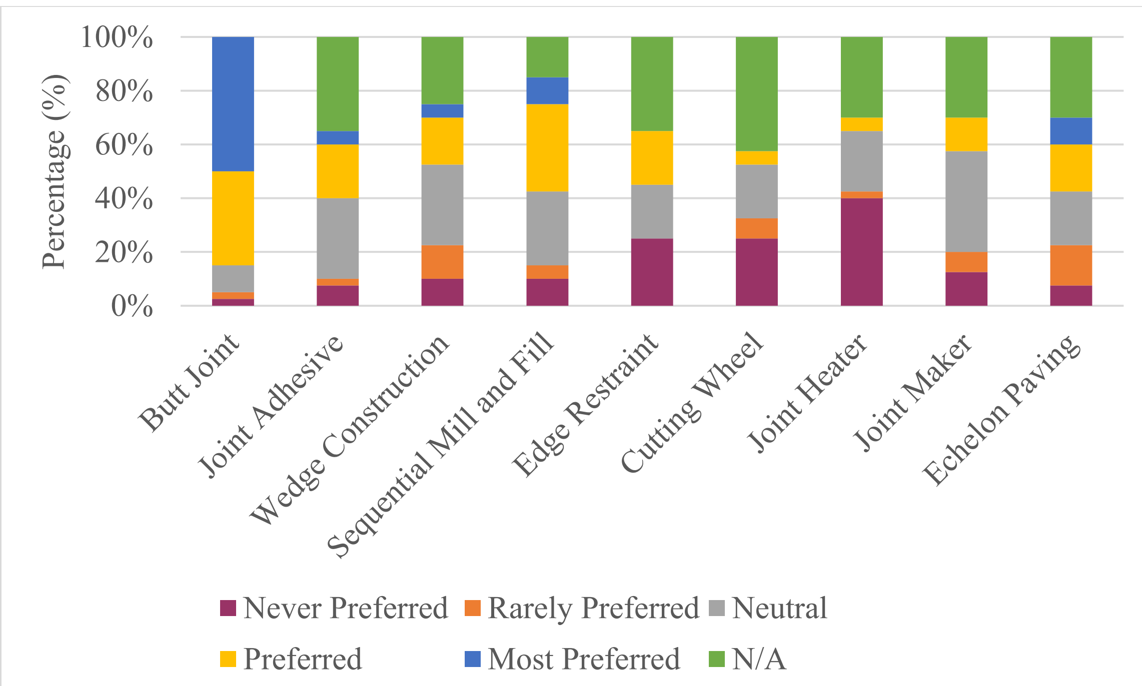

Figure 3.10: Preference rating of joint construction techniques

When the respondents were asked why certain construction practices perform better than other practices, 1 contractor answered that more overlapping is performed on wedge and another responded that joint adhesive increases bonding between the existing lane and the new lane. Because South Carolina does not experience freezing temperatures often, 1 contractor concluded a butt joint technique performs well.

In response to the better performance question by SCDOT personnel, 2 explained echelon paving works the best because asphalt is being pulled on both lanes while the mix is still hot enough to connect two lanes into one. Another 2 personnel explained joint adhesive performs better than others because it assists with cohesion at the joint by increasing the bonding strength. With sequential mill and fill, 1 respondent explained that the hard-compacted edge to compact against improves the compaction of the new asphalt and allows better packing. Any technique with a confined edge will not produce loose material at the joint (1 response) compared to the unconfined edge. Another respondent added that mill and fill does not require hand work and emphasized that hand work worsens the performance of the joint. For notched wedge joint construction, 1 mentioned that it allows better compaction on the edge. All of the survey takers' performance rating of the specific construction methods based on visual, permeability or density observation are presented in Figure 3.11.

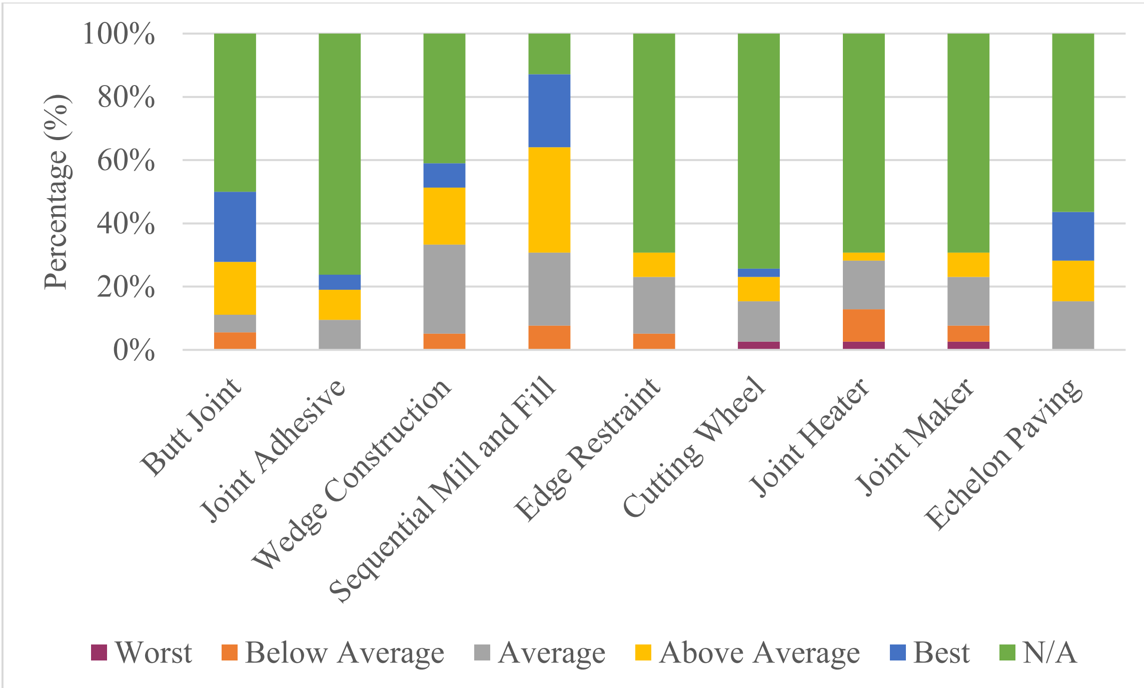

Figure 3.11: Performance rating of the joint construction technique

There are many factors that influence the quality of longitudinal joints in asphalt pavements and survey participants were asked about their opinions about the most important factors. Contractors answered tacking the joint (2 responses), compacting at hot temperature (2 responses), matching of the joint properly (2 responses), ensuring the joint is clean (1 response), and minimizing the luting movement (1 response). The SCDOT personnel responses to the important factors that influence the quality of joints included:

- Proper compaction efforts at the joint (13 responses)
- Straight joint alignment (9 responses)
- Proper temperature and timing (7 responses)

- Clean and leveled joint (6 responses)
- Lute movement (6 responses)
- Adequate material at the joint (6 responses)
- Proper application of tack coat at edge (6 responses)
- Offsetting joints among layers (2 responses)
- Application of adhesive (1 response)
- Prep work prior to paving (1 response)
- Attention to detail (1 response)
- Grade (1 response)
- Depth (1 response)

Recommendations

As part of the survey, the participants were asked to provide any recommendations on improving the quality of future longitudinal joints in asphalt pavements. From the contractor responses, 1 suggested that a best practice guide be developed as a referral instead of developing a specification and another noted that managing the paving crews to follow the best practices of compacting and matching. From the SCDOT responses, 8 participants suggested there should be specific contract requirement or specification on longitudinal joint construction. Some of the suggested specification requirements included the use of rubber tire for compaction, gurantee overlap of material over the joint, use of a physical string line, restriction on poor joint techniques, and increase in inspection emphasis. Six SCDOT personnel reemaphsized clean, striaght joints with proper tack coat and luting of the joint. Four survey takers replied training and recertification for roller operators should be necessary because paving crews are becoming less experienced. Two SCDOT respondents noted that the mill and fill method should be used instead of overlaying the edge. Since South Carolina does not have enough experience with using other joint construction techniques, 2 respondents recommended conducting more studies on the effectiveness of other methods and evaluating the quality of construction. One person emaphsized the use of joint adhesive and utilization of more wedge markers because they are the easiest option to implement in the future. Other indiviual recommendations included taking additional time to prepare the joints, planning operations ahead of time, compacting the edges, and using the cold rolling technique.

CHAPTER FOUR

RESEARCH METHODOLOGY

The goal of this research was to evaluate the relative quality of longitudinal joints compared to interior portions of pavements in South Carolina. The comparison was made by performing field and lab measurements of density, permeability, and indirect tensile strength (ITS) at the longitudinal joint and adjacent lanes (hot and cold lanes) after construction. This chapter describes the experimental procedures followed to collect the data used in this study. The test plan sequence and procedures are shown in Figure 4.1

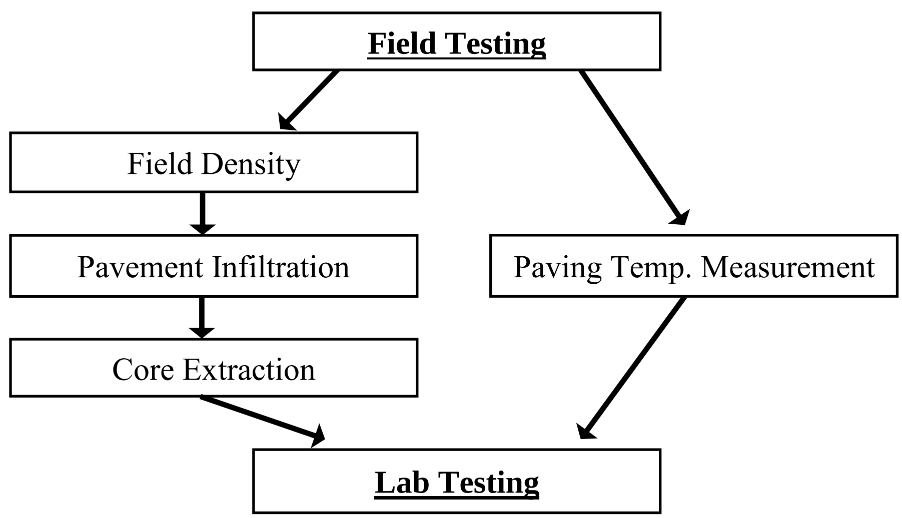

Figure 4.1: Field test plan sequence and procedures

Field Testing

During pavement construction, several qualitative observations and quantitative measurement were made related longitudinal joint construction (Table 4.1).

Table 4.1: Field testing procedure summary

Field Testing	**Method**	**Frequency / Timing**	**Reason**
Joint Temperature	Use an infrared thermometer to measure the hot and cold lanes after paver has passed and measure the hot lane again right before the first roller pass	100 ft intervals	Determine the change in temperature right before compaction
In-Place Pavement Density	Use a PQI density gauge to measure density across the width of pavement	10 readings across the lane width	Compare field density at the joint to the remainder of pavement
In-Place Pavement Infiltration	Use a field permeameter at core locations to determine field infiltration	1 min testing at each core location	Compare field infiltration at the joint and the hot lane
Pavement Coring	Determine the thickness of surface course and use a coring rig to cut cores	2 or 3 cores per station	Take cores back to laboratory for lab testing

Joint Temperature

The temperature of the pavement was measured on the hot and cold lanes as soon as asphalt was placed. The temperature of the hot lane was recorded again right before the first roller pass. For theses measurements, a laser infrared thermometer, which has an accuracy of plus or minus 1 degree Celsius, was pointed roughly 2 ft off the ground and 1 ft away from the joint for the hot and cold lanes (Figure 4.2). The distance between each measuring point was set at 100 ft intervals and the distance was measured using a measuring wheel. Depending on the speed or delay of a roller on a construction site, the distance of the next measuring point was extended to 200 or 300 ft. At least four temperature measurements were taken depending on the speed of a paver. For the SC 8 project, temperature was measured after the first roller pass due to safety reasons.

Figure 4.2: Measuring joint temperature

In-Place Pavement Density

The in-place density of the pavement was measured following the finish roller passes. The density readings were recorded using a density gauge and measurements were taken across the width of a pavement as shown in Figure 4.3 and Figure 4.4 to obtain the transverse density profiles. The in-place density reading was recorded on the hot and cold lanes and near joint if traffic or a quality control manager allowed. A Troxler nuclear density gauge was only used for the first US 25 project visit and a non-nuclear density gauge, Pavement Quality Indicator (PQI) 380, was used for the rest of the projects.

A nuclear density gauge contains radioactive material and it determines field density by detecting amount of gamma radiation passing through the asphalt pavement (Troxler 2009). A PQI 380 uses impedance spectroscopy to measure the electrical response of asphalt and calculate density. The PQI 380 is primarily used for newly-laid asphalt pavement with thickness ranging from 0.75 in to 6 in (Transtech 2016). Because the surface at a joint is typically uneven, the closest density gauge reading to the joint was centered at 1 ft away from the joint. The location of the first station tested was determined by the quality control manager's coring location based on SC-T-101 (SCDOT 2013). Additional measurements were taken 100 ft and 200 ft from the first station, in the direction of paving.

Figure 4.3: In-place, non-nuclear density gauge

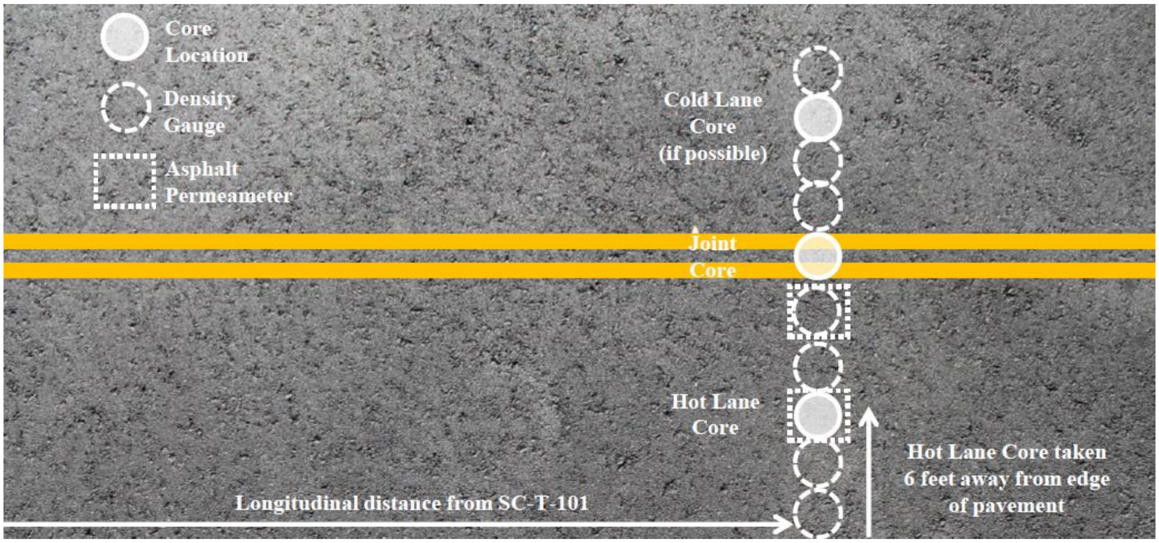

Figure 4.4: Testing plan on a constructed pavement

In-Place Pavement Infiltration

Pavement infiltration, the final field test, was conducted before coring samples from the pavement. The in-place infiltration was tested at the coring locations using the NCAT Asphalt Field Permeameter (shown in Figure 4.5) in accordance with the operating manual. The in-place infiltration test for joint sections was centered 1 ft away from the joint on the hot lane due to an uneven surface that resulted in water leaking through seal between the permeameter and pavement surface. The Gilson NCAT field permeameter kit operating manual specified applying gentle, uniform foot pressure without twisting it to force the sealant into the asphalt mat (2013). In this study, water continued to leak without twisting to force the sealant into the asphalt mat, therefore, the permeameter was twisted slightly as it was sealed to the pavement. Additionally, the upper tier, which was included in the permeameter kit, was not utilized due to the water leaking through seal between the upper tier and bottom tier of permeameter. When calculating the field infiltation at the core locations, the permeability equation was not used due to the limited information on the thickness of the pavement. Instead, the infiltration rate was calculated using Equation 4.1.

$$Inf = \frac{a(h_1 - h_2)}{At} \tag{4.1}$$

Where: Inf = infiltration; a = inside cross-sectional area of the graduated cylinder; t = elapsed time between h_1 and h_2; and h_1 = initial head, h_2 = final head

Figure 4.5: In-place pavement infiltration

Pavement Coring

Pavement cores were taken at each test station at the longitudinal joint and center portion of the lane as illustrated in Figure 4.6. If there was a multiple lane closure, a core from the adjacent cold lane was also taken without disrupting traffic. To mitigate biased results, the longitudinal location of the first testing and coring location coincided with the random location of the contractor's acceptance cores as determined as per SC-T-101. The transverse location for the hot lane core was the center the lane (i.e., 6 ft from the edge of the lane). Additional test stations (density, permeability, and coring) were located 100 ft and 200 ft downstream from the first location. If the quality control manager was not required to cut cores, then the first station was determined at 500 ft from the starting point of paving that day. The size of the field cores was 150 mm (6 in.) in diameter and thickness of cores varied from pavement to pavement. The cores were transported to Clemson University packed in a cooler of ice. The bottom of each core was trimmed using a masonry saw with a diamond tipped blade to remove the tack coat and other adhered material (Figure 4.7). The trimmed cores were placed in an automatic core drying unit (Figure 4.8) to dry and prepare for lab testing.

Figure 4.6: Cutting a pavement core

Figure 4.7: Trimming a bottom part of pavement core

Figure 4.8: Core drying unit

Laboratory Tests

The pavement cores from the joint and the interior of two adjacent lanes were used to compare the relative quality and performance of longitudinal joints. The comparison was made by comparing the density, permeability, and indirect tensile strength (ITS) of pavement cores obtained at each test station. The comparison among different paving projects was also made to analyze any influence of different construction and compaction methods on the longitudinal joint quality. The procedures included in Figure 4.9 were used to evaluate the quality of the longitudinal joints.

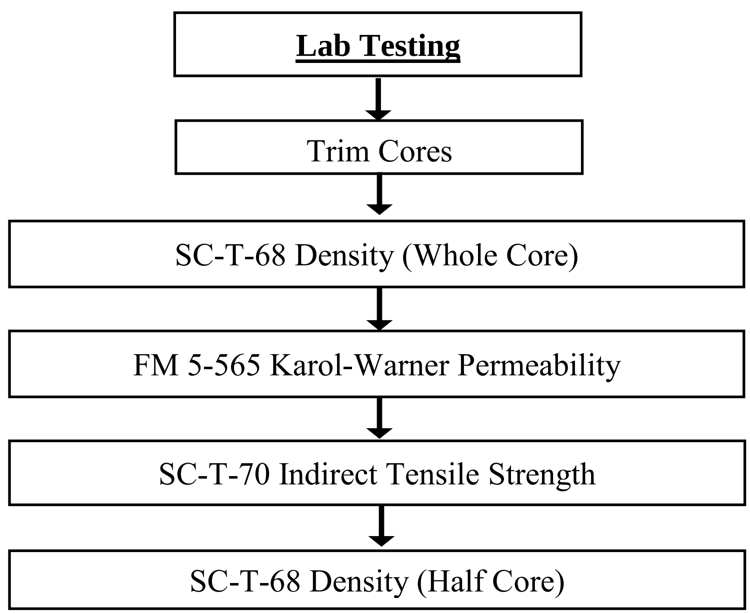

Figure 4.9: Laboratory test plan sequence and procedures

Density

After drying with the automatic core dryer, the bulk specific gravity (G_{mb}) and density of each core was measured in accordance with SC-T-68. After conducting indirect tensile strength tests, the density of each half core was also measured using the same procedure to compare density of the hot and cold lanes at the joint. The G_{mb} of the cores was calculated using Equation 4.2:

$$G_{mb} = \frac{A}{B - C} \tag{4.2}$$

where: G_{mb} = bulk specific gravity; A = mass of dry core in air; B = mass of core in saturated surface dry (SSD) condition; C = mass of core under water.

Permeability

A falling head permeameter (Figure 4.10) was used to measure the permeability of each core in the lab according to the FM 5-565 procedure out lined by the Florida DOT (2004). This procedure calls for the permeability to be determined by recording time required for 500 ml of water to flow through the specimen under a specific head. This study deviated from FM 5-565 procedure, in that if the time exceed 30 minutes to complete the test in the first trial, the change in the head after 5 minutes was measured in the second trial. The coefficient of permeability, k, is based on Darcy's law and was calculated using Equation 4.3:

$$k = \frac{aL}{At} \ln\left(\frac{h_1}{h_2}\right) * t_c \tag{4.3}$$

where: k = coefficient of permeability; a = inside cross-sectional area of the graduated cylinder; L = average thickness of the core; t = elapsed time between h_1 and h_2; h_1 = initial head, h_2 = final head; and t_c = temperature correction for viscosity of water.

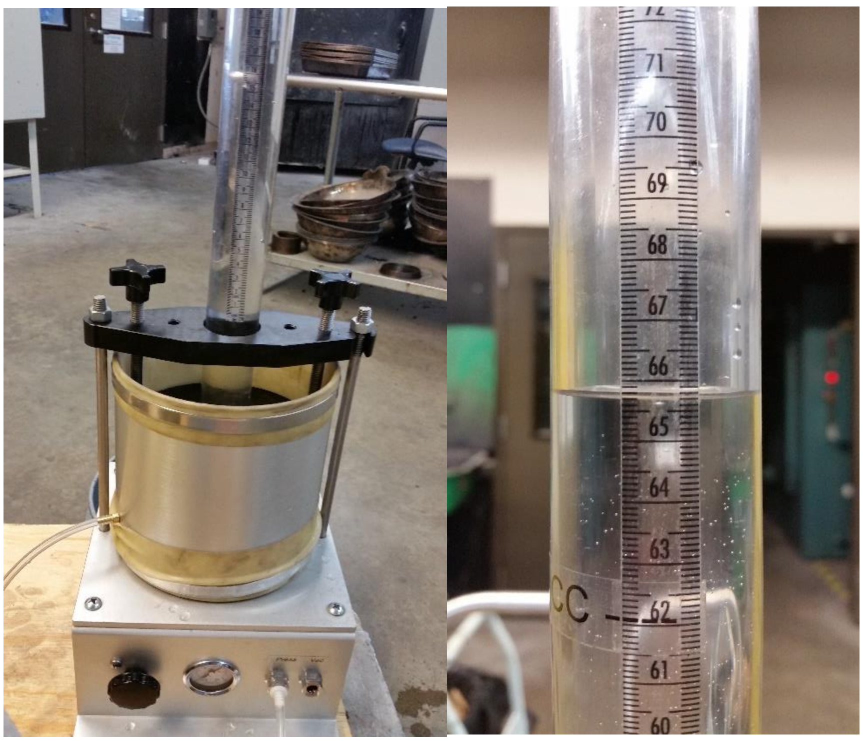

Figure 4.10: Falling head permeameter

Indirect Tensile Strength

The indirect tensile strength (ITS) of cores taken from the field was measured following SC-T-70 to determine the strength of each core. The ITS information can also be used as an indicator of adhesion between cold and hot lanes for joint cores (Huang et al. 2010). When testing a core (joint or interior), the specimen was positioned in the test fixture so the direction of traffic was oriented vertically (i.e., in the direction of loading).

This ensured that when the joint cores were tested, the joint was aligned with the load to apply tensile forces directly to the joint (Figure 4.11). The ITS was calculated using Equation 4.4:

$$ITS = \frac{2\,(L)}{\pi(H)(D)} \tag{4.4}$$

where: L = maximum load applied; H = height of the core; D = diameter of the core.

Figure 4.11: Indirect tension strength test

After splitting the joint cores for the ITS testing, the density of the cold side and hot side of the broken cores were measured again per SC-T-68.

CHAPTER FIVE

RESULTS AND DISCUSSION

Project Locations

All of the data for this research was from 9 asphalt construction projects, which were completed in South Carolina DOT Districts 1, 2, and 3 at the locations indicated in Figure 5.1. The projects evaluated in this study included 3 different surface type mixes (surface type A, B, and C), 2 longitudinal joint construction techniques, and 1 rolling pattern (hot overlap).

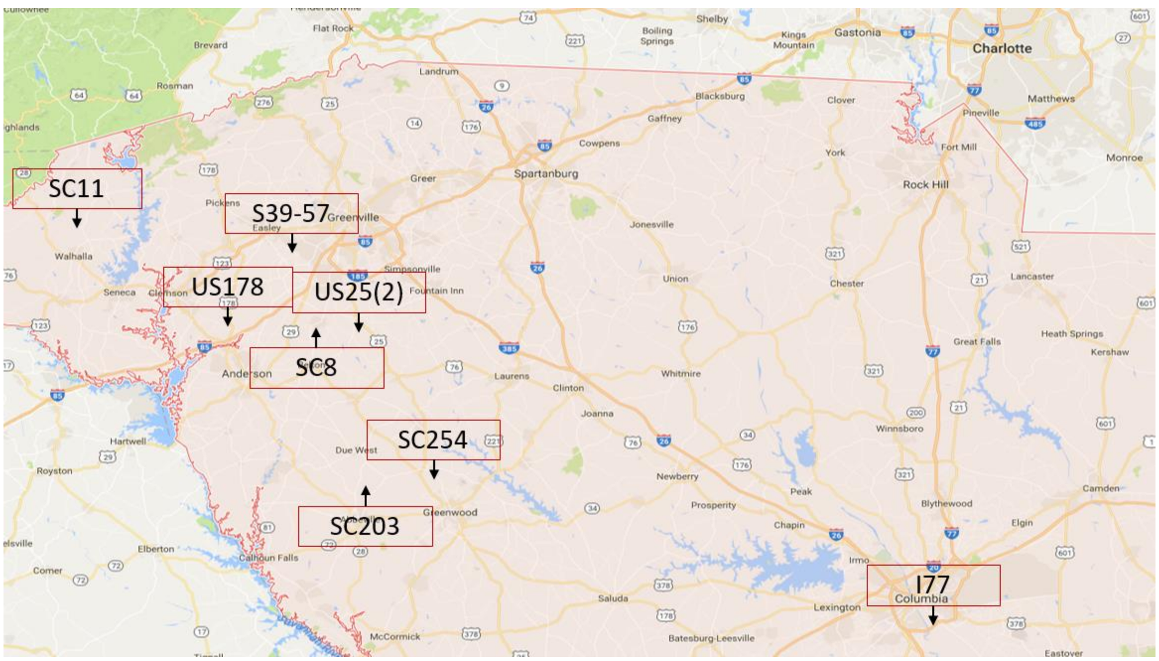

Figure 5.1: Locations of projects evaluated in this study

Projects

Project Table and Figure Labels

For each section of the project, there will be tables with construction information and, bar and line charts that consist of temperature readings, in-place density, in-place infiltration, lab density, lab permeability, ITS, and half core lab density results. To clarify what each label represents, descriptions are included below.

In the construction information of each project, “joint straightness” describes if the joint was constructed straight, straightish, or not straight. To determine straightness of the joint, a visual observation was made for each project. The “height of joint” indicates the height of the overlapped material at the joint after the paver passed by. The “extent of joint” means the distance between the end gate of the paver screed to the top edge of unconfined surface.

For the pavement temperature figures, the “hot after pave” and the “cold after pave” labels represent the temperature of hot lane and cold lane, respectively, after the paver passed. Likewise, the “hot before compact” represents the hot lane temperature right before the roller passed. On the x-axis, 0 percent is where the joint is located and 100 percent is the other edges of the lane. If the figure has negative percent and the positive percent, the negative percent indicates the hot lane and the positive percent indicates the cold lane.

The “hot, joint, and cold” labels that are shown in density, air void contents, infiltration, permeability, and indirect tensile strength (ITS) figures represent the cores taken from the middle of the hot lane, the joint, and the middle of the cold lane, respectively. In project half core density figures, the "half hot" and the "half cold" represent the hot side and the cold side, respectively, of the joint core after conducting the ITS test and the "whole joint" represents the density of the joint core before the ITS test.

In the summary of projects tables and figures, J/H represent the average ratios of joint and hot lane measurement of each station. The J/H ratios help to compare the performance of the joint relative to interior of the mat at each station instead of comparing average joint and hot lane measurement of all stations. The C/H represents the average ratios of cold lane and hot lane measurement of each station.

US 178 Project

The US 178 Project was constructed using a butt joint technique and information for construction, mix design, and gradation can be found in Table 5.1. Due to safety reasons and other technical issues, some of the construction information in the table could not be obtained. The temperature readings, in-place density, lab density, air void content, lab permeability, ITS, and half core lab density results from this project are presented in Figures 5.2 through 5.8. The summary of all the US 178 results is presented in Table 5.2.

Note: The distance between each temperature reading was approximately 25 - 50 ft. The field infiltration could not be performed due to water leaking through the seal after multiple trials.

Table 5.1: US 178 project information

Construction Information	
Location	US-178
Construction Type	Butt Joint
Compaction at Joint (First Pass)	Hot Overlap
Thickness	2 in
Joint Straightness	Not straight
Joint Cleanness	Clean
Joint Tack Coat	Unknown
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	Yes
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	2.9
Target AC (%)	5.7
Average MSG	2.523
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	91.0
4.75 mm (No. 4)	63.0
2.36 mm (No. 8)	47.0
0.60 mm (No. 30)	30.0
0.150 mm (No. 100)	10.3
0.075 mm (No. 200)	5.4

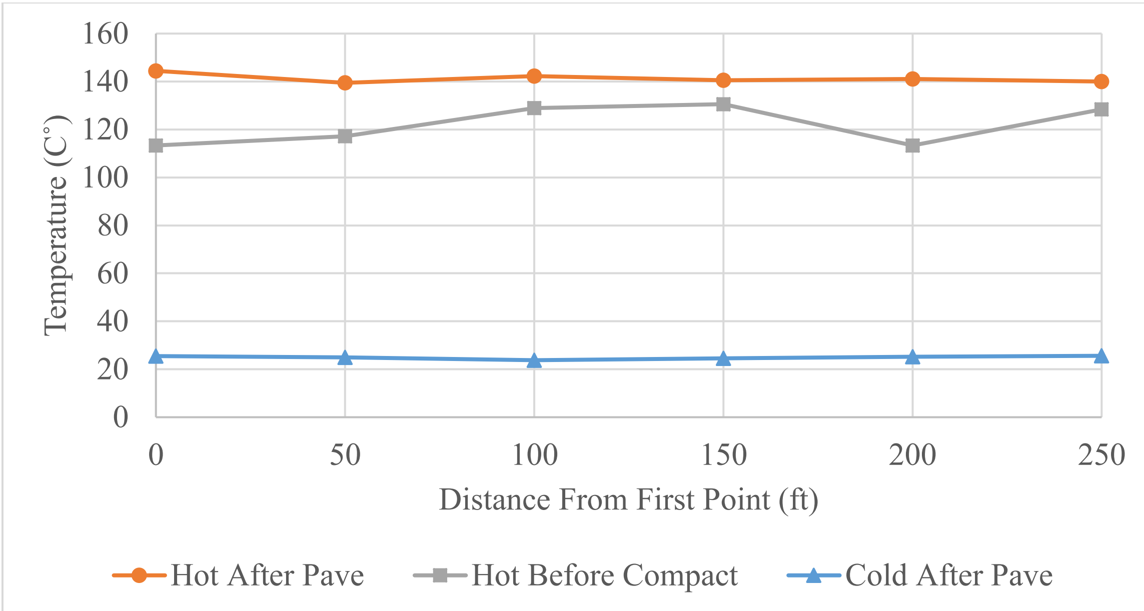

Figure 5.2: US 178 project pavement temperature

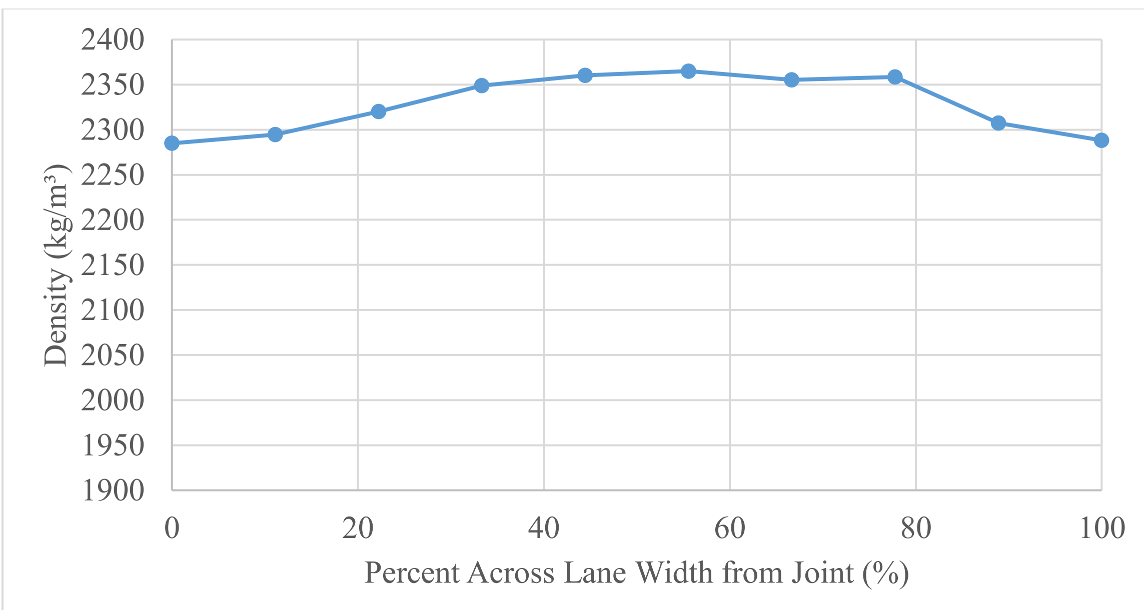

Figure 5.3: US 178 project in-place density measurement (measured with the PQI)

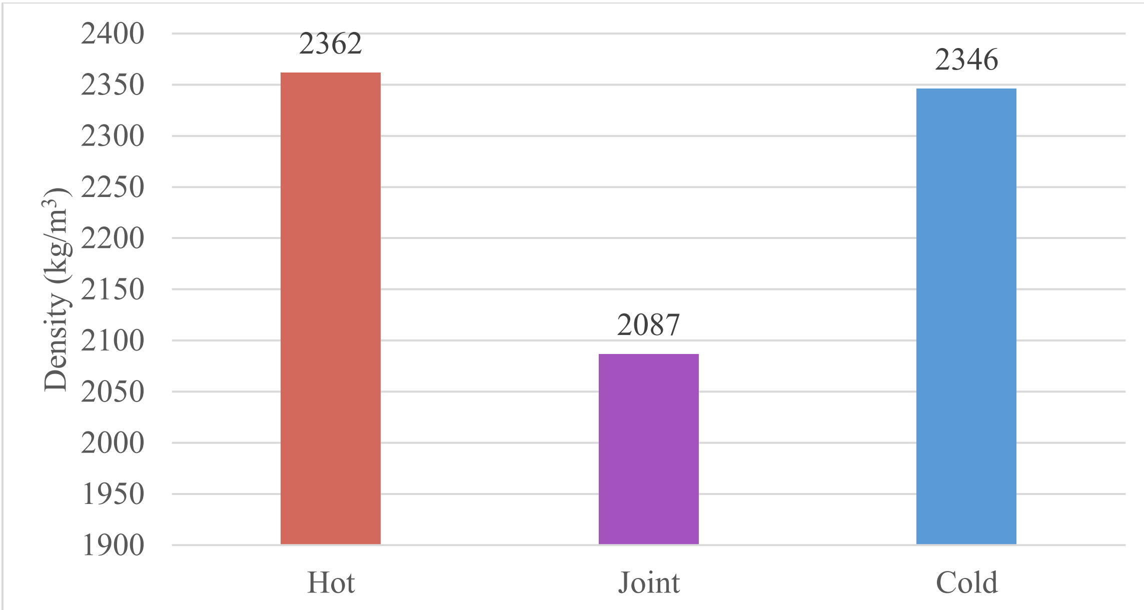

Figure 5.4: US 178 project lab density measurement

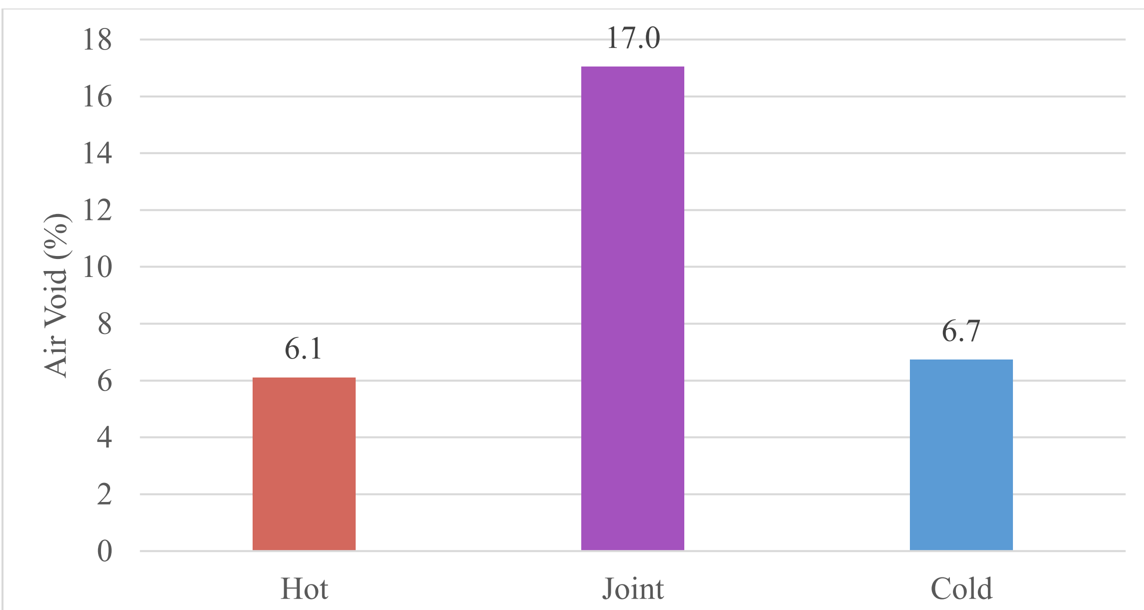

Figure 5.5: US 178 project air void contents

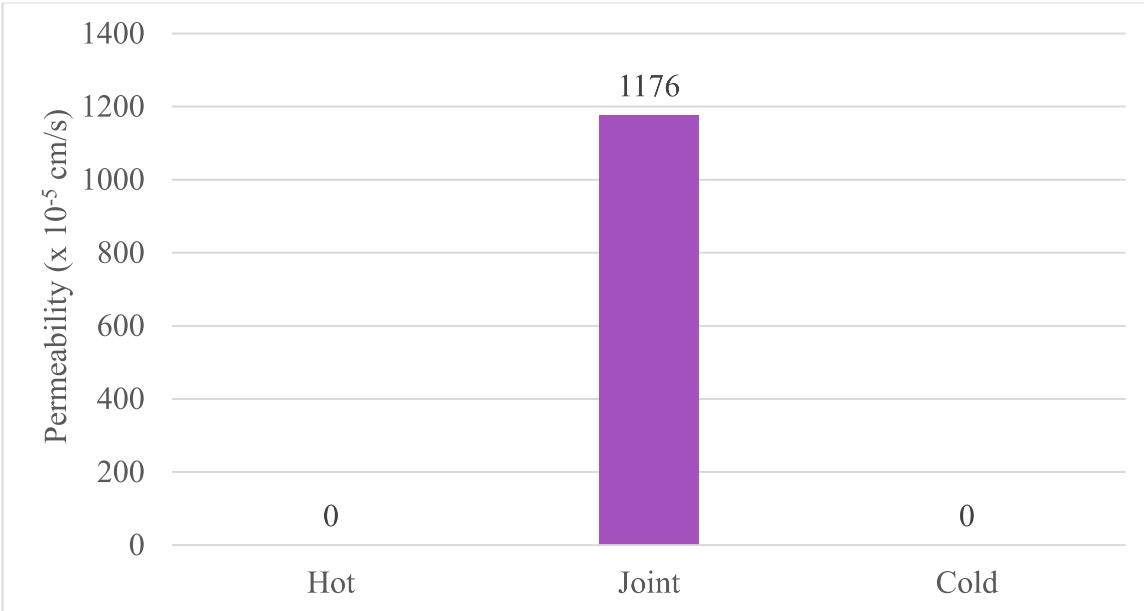

Figure 5.6: US 178 project lab permeability

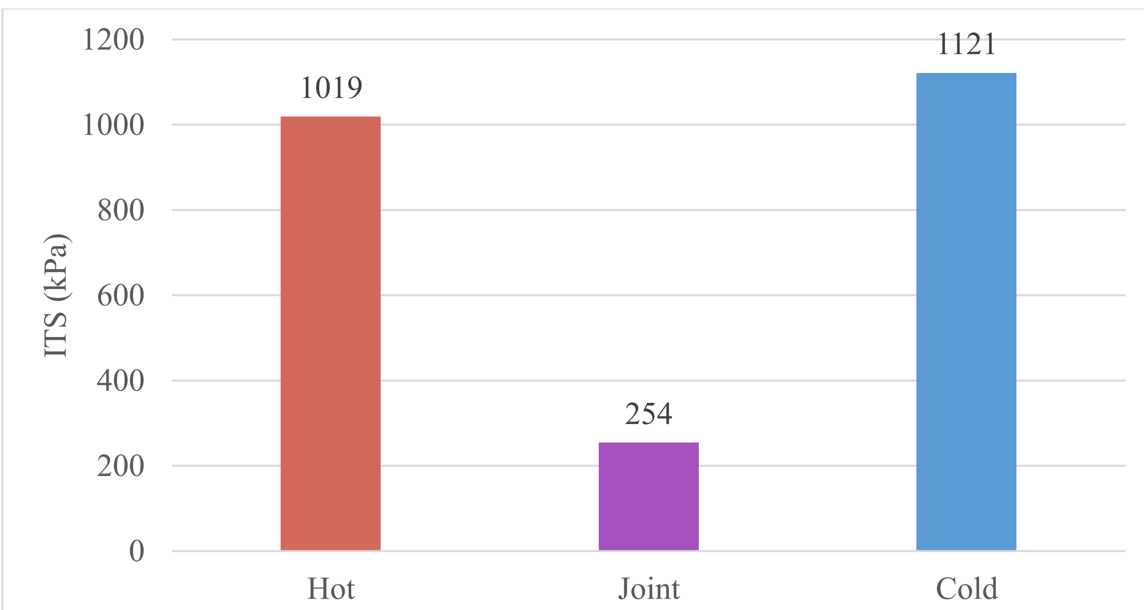

Figure 5.7: US 178 project dry indirect tensile strength (ITS) measurement

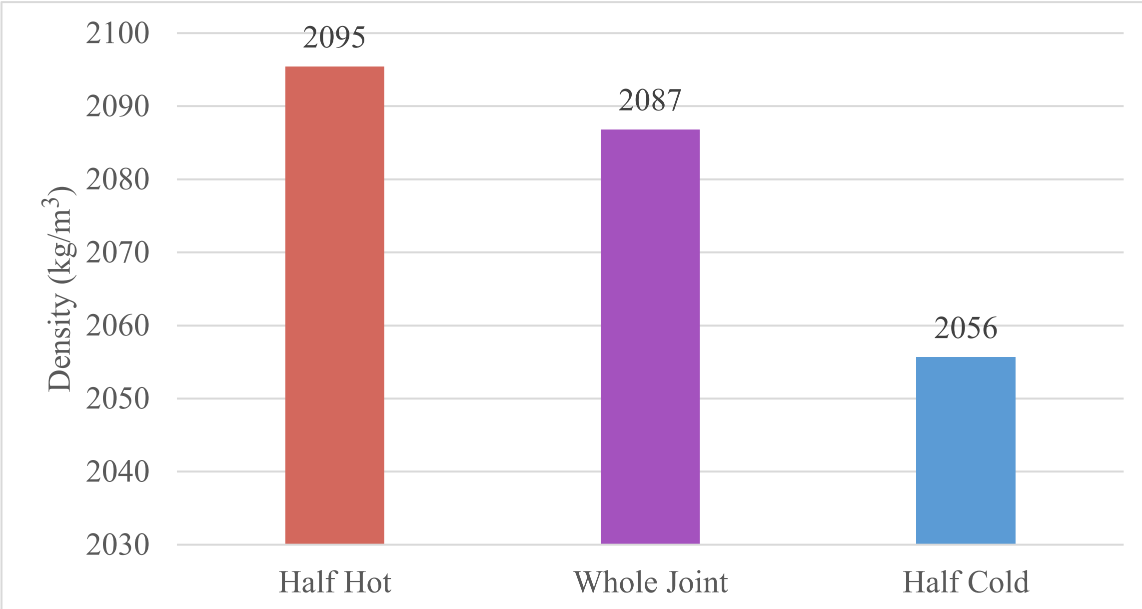

Figure 5.8: US 178 project half core lab density from the joint core

Table 5.2 Summary of US 178 project

(H = hot lane or half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2363	2285	.	N/A
Field Infiltration (x 10^{-5} cm/s)	.	.	.	N/A
Lab Density (kg/m³)	2362	2087	2346	N/A
Lab Air Void (%)	6.1	17.0	6.7	N/A
Lab Permeability (x 10^{-5} cm/s)	0	1164	0	N/A
ITS (kPa)	1019	254	1121	N/A
Half Lab Density (kg/m³)	2095	.	2056	N/A

For the US 178 project, only 3 cores (the hot lane, joint, cold lane) were taken from one station and therefore, a statistically analysis to compare the performance between the hot lane and the joint could not be performed. However, based on the results presented in Figures 5.3 through 5.8, results, the performance of the joint was consistently poorer than the hot lane. The field density at the joint and the free edge was lower than the field density at middle of the hot lane, forming a flat bell-shaped curve. In comparison to the field density result, the lab density at the joint is much lower than the lab density of the hot and cold lane. The lab permeability of the cores taken from the hot lane and the cold lane was almost impermeable, but the joint had a high permeability. The ITS result also shows that the indirect tensile strength at the joint was much lower than the hot and the cold lanes. The hot and cold lane had similar results in all tests.

The lab results in Table 5.2 could be negatively influenced by not icing the surface of coring locations before cutting the cores. It is important to ice the area of interest before coring since the hot asphalt mix may still be hot enough to deform while coring. This was a nighttime paving project and there was limited visibility for paving or rolling operators to identify the joint up ahead and the poor visibility could have caused poor compaction of the joint.

SC 203 Project

The SC 203 overlay was constructed using a safety edge and no compaction was performed on the edge. The safety edge is a sloped pavement edge at the joint, which improves safety of drivers by eliminating a vertical drop off the edge when they are changing a lane from the paved lane to the milled, unpaved lane. It was noted that the joint on SC 203 was compacted first using the hot overlap method and then the hot pinch method on the second pass. The background information that includes construction, mix design, and gradation can be found in Table 5.3. Due to technical problems, limited time, and traffic, some of the construction information could not be obtained. The temperature readings, in-place density, lab density, air void contents, in-place infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density taken from this project are presented in Figures 5.9 through 5.16. The summary of all the SC 203 results is presented in Table 5.4.

Note: The field density was only recorded at station 252+10 and the field infiltration at 255+10 could not performed because of limited time and limited amount of traffic control. The cores taken from this project were cut by the onsite quality control manager who used a 145 mm (5.7 in) inner diameter core bit, which was smaller compared to the Clemson research core bit size used on the other projects. The ITS for the hot core at station 253+10 could not be performed because the specimen was not cut with the joint in the center. The numerical values with stars not included in the statistical analysis because cores were not cut right on the joint.

Table 5.3: SC 203 project information

Construction Information	
Location	SC-203
Construction Type	Safety Edge
Compaction at Joint (First-Second))	Hot Overlap - Hot Pinch
Thickness	1.75 in
Joint Straightness	Straightish
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface C
AC Grade	PG 64-22
Design Air Voids (%)	3.6
Target AC (%)	5.5
Average MSG	2.434
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	100.0
9.5 mm (3/8")	95.1
4.75 mm (No. 4)	68.7
2.36 mm (No. 8)	47.8
0.60 mm (No. 30)	26.2
0.150 mm (No. 100)	9.9
0.075 mm (No. 200)	4.5

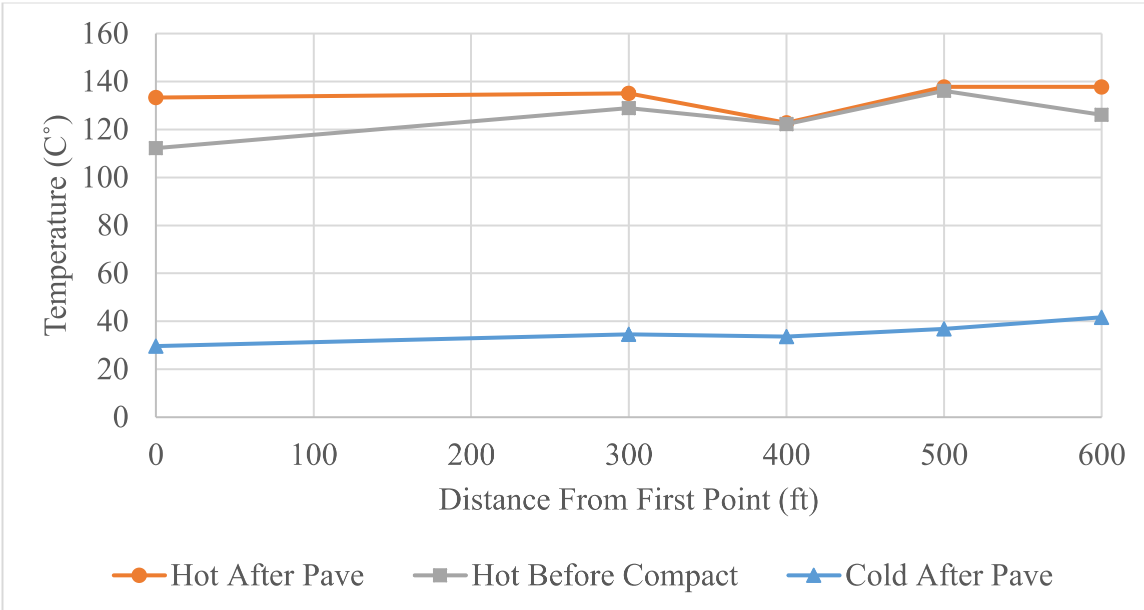

Figure 5.9: SC 203 project pavement temperature

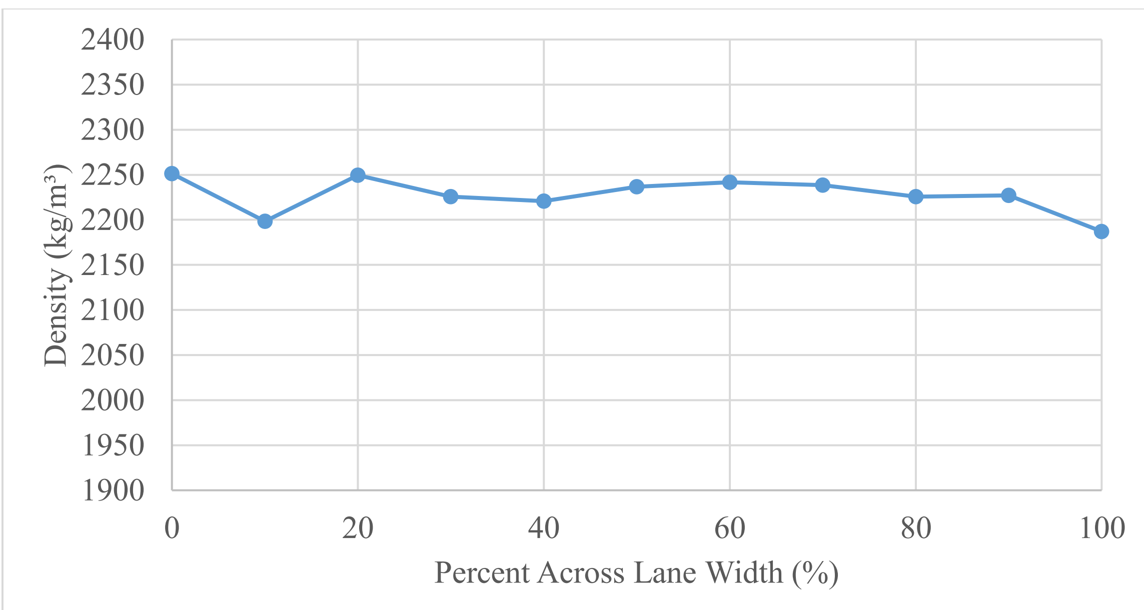

Figure 5.10: SC 203 project in-place density measurement (measured with the PQI)

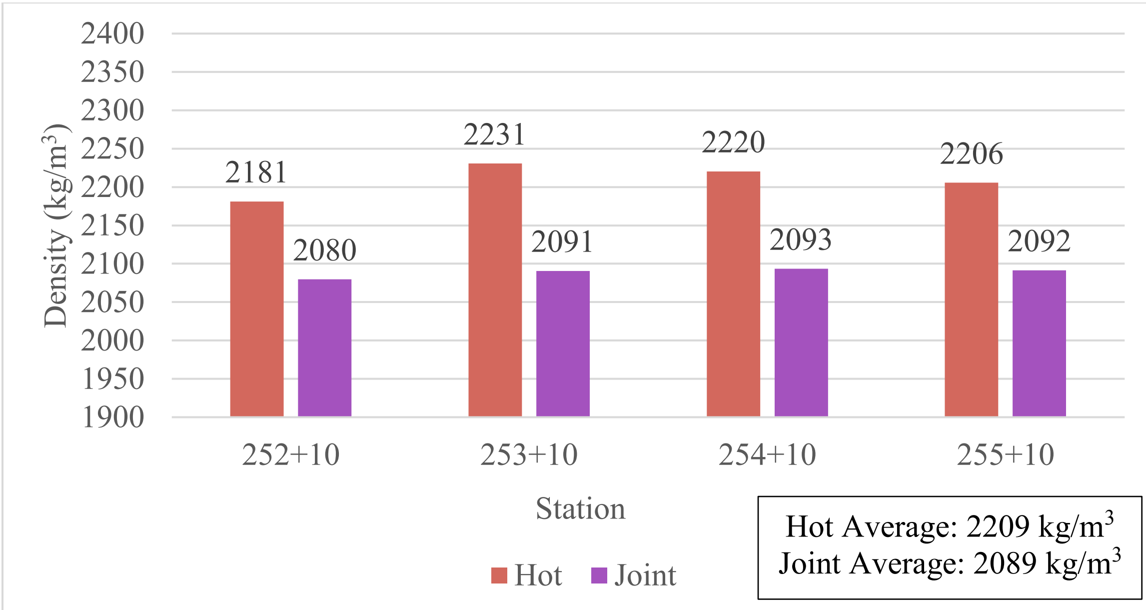

Figure 5.11: SC 203 project lab density measurement

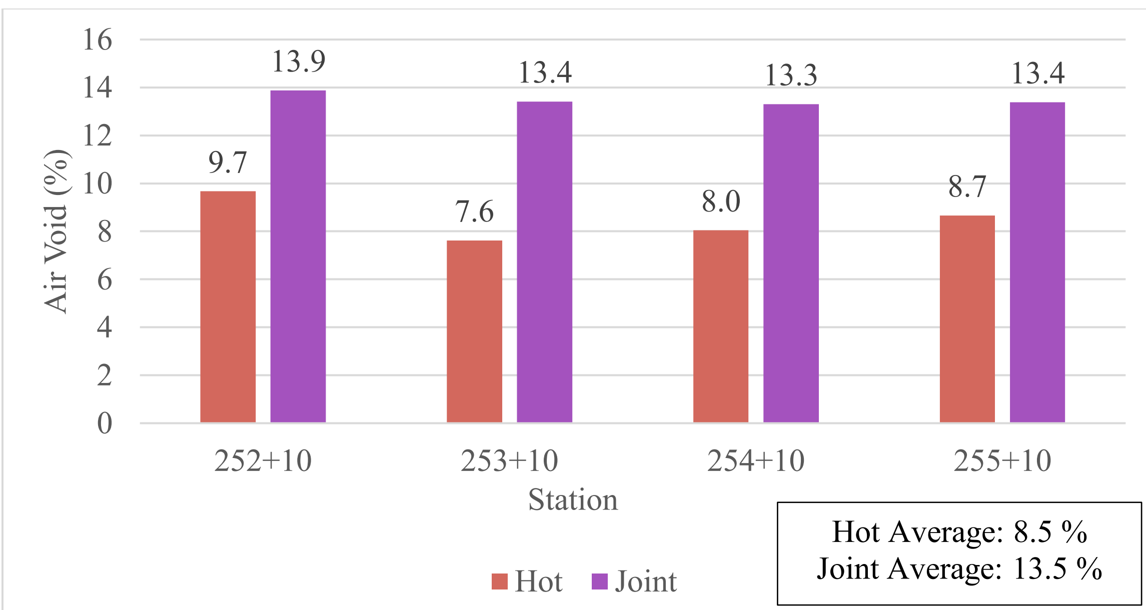

Figure 5.12: SC 203 project air void contents

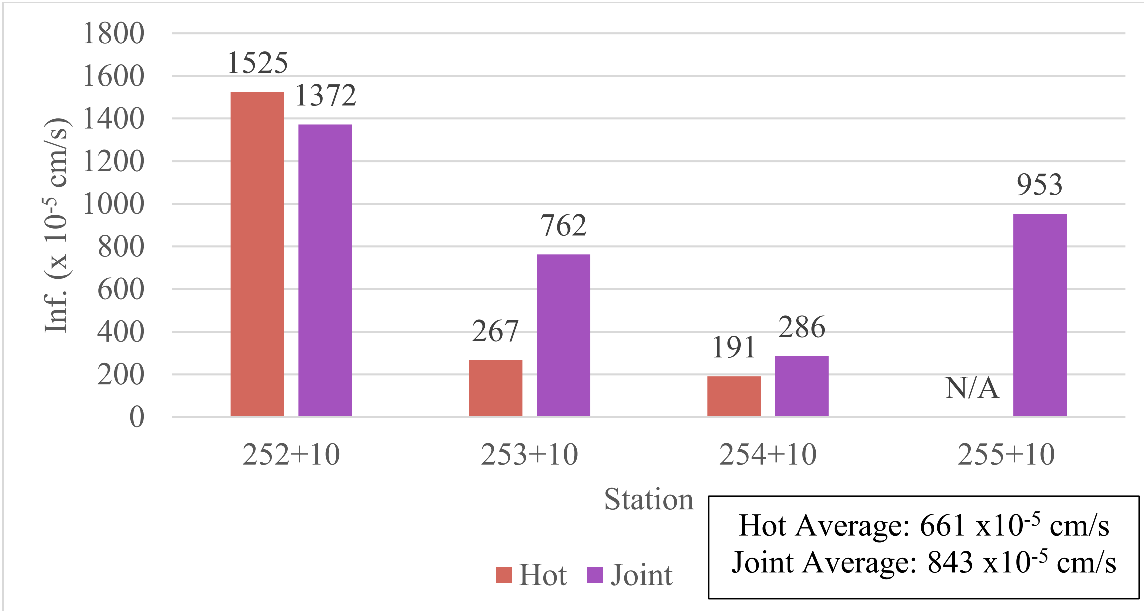

Figure 5.13: SC 203 project in-place infiltration measurement

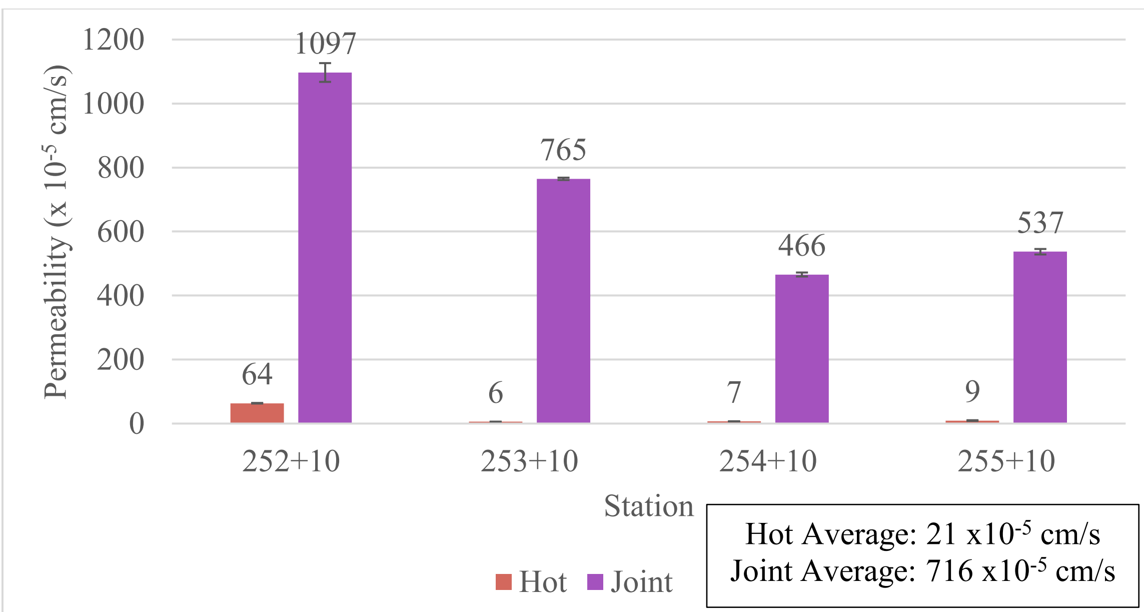

Figure 5.14: SC 203 project lab permeability

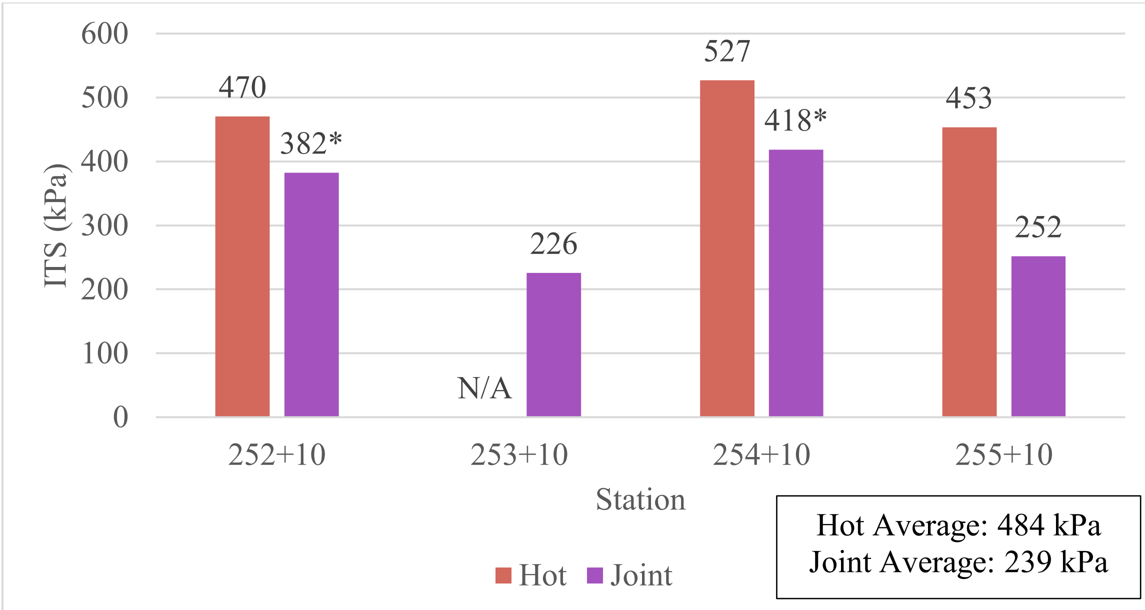

Figure 5.15: SC 203 project dry indirect tensile strength (ITS) measurement

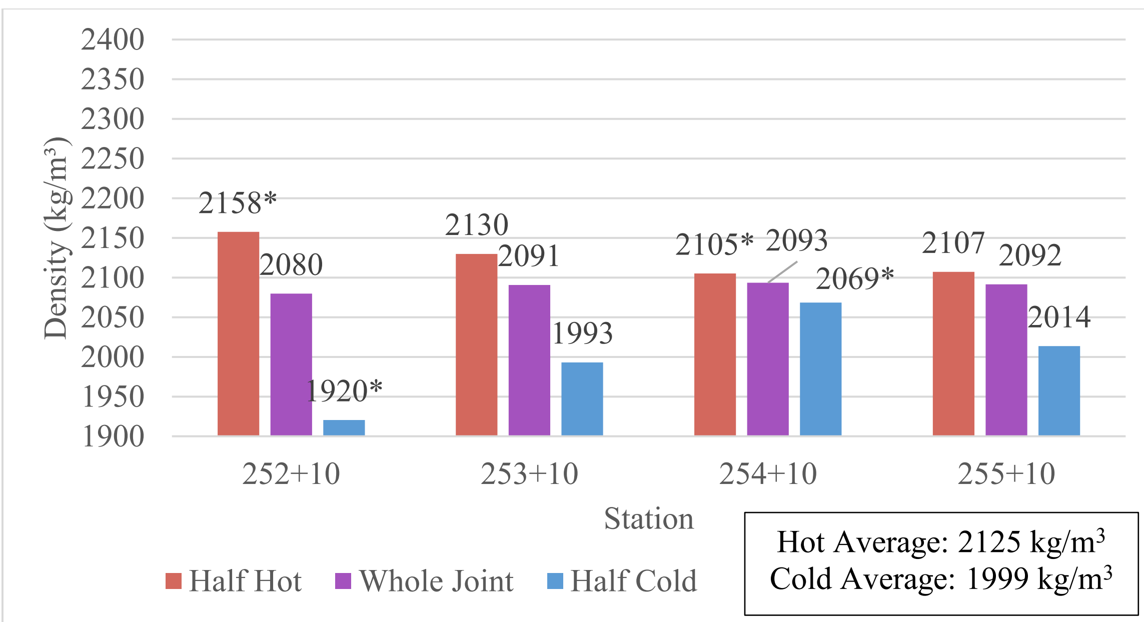

Figure 5.16: SC 203 project half cores lab density from the joint cores

Table 5.4: Summary of SC 203 project

(H = hot lane or half hot, J = joint, C = half cold, N/A = limited data)

Average	Hot	Joint	Cold	Significant Difference
Field Density (kg/m³)	2226	2224	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	661	843	.	No (H vs J)
Lab Density (kg/m³)	2209	2089	.	Yes (H vs J)
Lab Air Void (%)	8.5	13.5	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	22	716	.	Yes (H vs J)
ITS (kPa)	484	320	.	N/A (H vs J)
Half Lab Density (kg/m³)	2125	.	1999	No (H vs C)

Significant differences between the hot lane and the joint were found in lab density, air void content, lab permeability, and ITS results at the 5% significance level. Therefore, the lab results from the SC 203 project show the performance of the joint cores was less than the hot lane cores. The same data trend was seen in the project as the US 178 project except for the in-place infiltration result at station 252+20. Additionally, the density of the halves from the joint cores showed significant differences between the hot lane core and the cold lane core, indicating the hot side of the joint core had statistically higher density compared to the cold side of the joint core. The hot side of the joint core will likely will have higher density than the cold side because the hot side had the confined edge during construction while the cold side did not.

US 25 Project

In SCDOT District 3, the surface layer of US 25 was constructed using a safety edge technique, but no special compaction was performed on the edge. The information for construction, mix design, and gradation can be found in Table 5.5. Some of the construction information could not be obtained because there was limited space or opportunity during construction. The temperature readings (Figure 5.17), in-place density (Figure 5.18), lab density (Figure 5.19), air void content (Figure 5.20), in-place filtration (Figure 5.21), lab permeability (Figure 5.22), indirect tensile strength (ITS) (Figure 5.23), and half core lab density (Figure 5.24) taken from this project are presented below. Table 5.6 provides a summary of all project data.

Note: The in-place density was measured using a Troxler nuclear density gauge instead of using a non-nuclear gauge. For all other projects, PQI non-nuclear gauge was used to measure in-place density.

Table 5.5: US 25 project information

Construction Information	
Location	US-25
Construction Type	Safety Edge
Compaction at Joint (First Pass)	Hot Overlap
Thickness	2.5 in
Joint Straightness	Straightish
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	3.1
Target AC (%)	5.7
Average MSG	2.433
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	90.0
4.75 mm (No. 4)	60.0
2.36 mm (No. 8)	45.0
0.60 mm (No. 30)	25.0
0.150 mm (No. 100)	8.0
0.075 mm (No. 200)	4.0

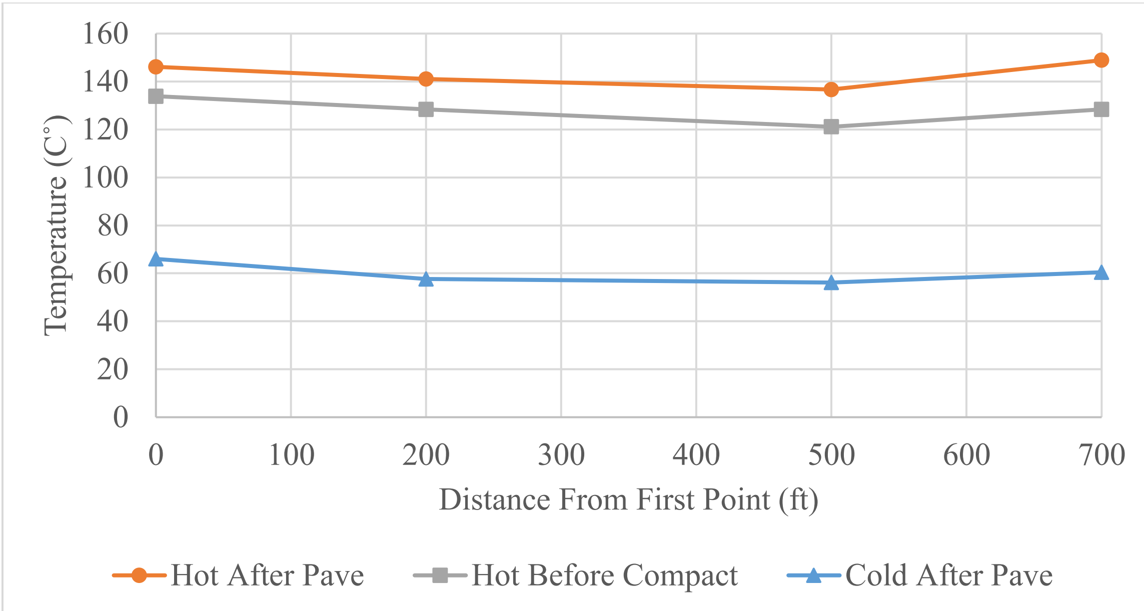

Figure 5.17: US 25 project pavement temperature

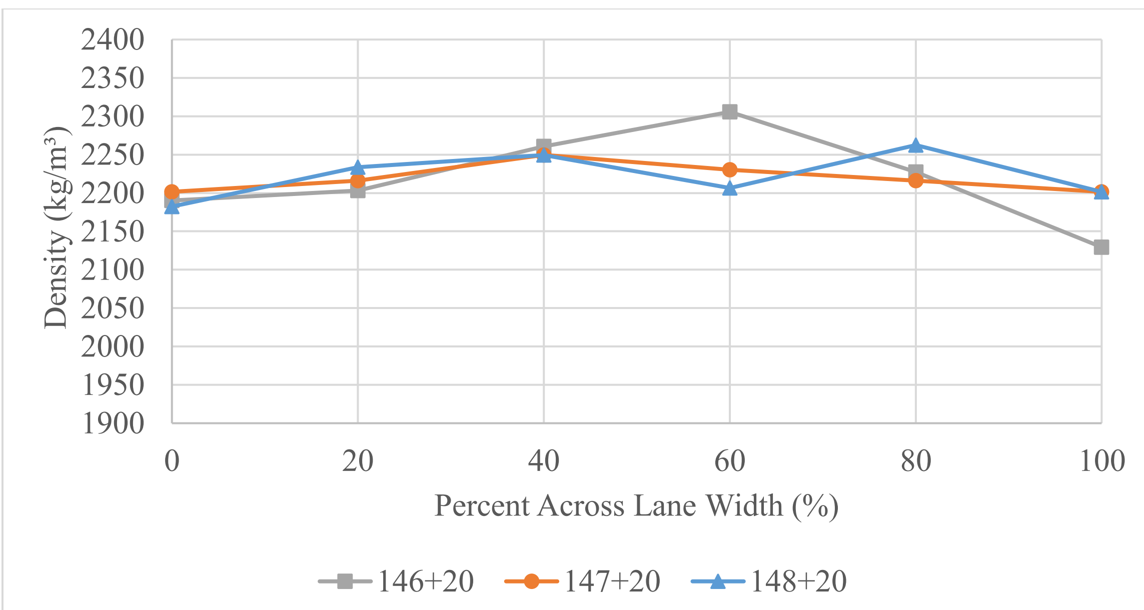

Figure 5.18: US 25 project in-place density measurement

(measured with the Troxler nuclear density gauge)

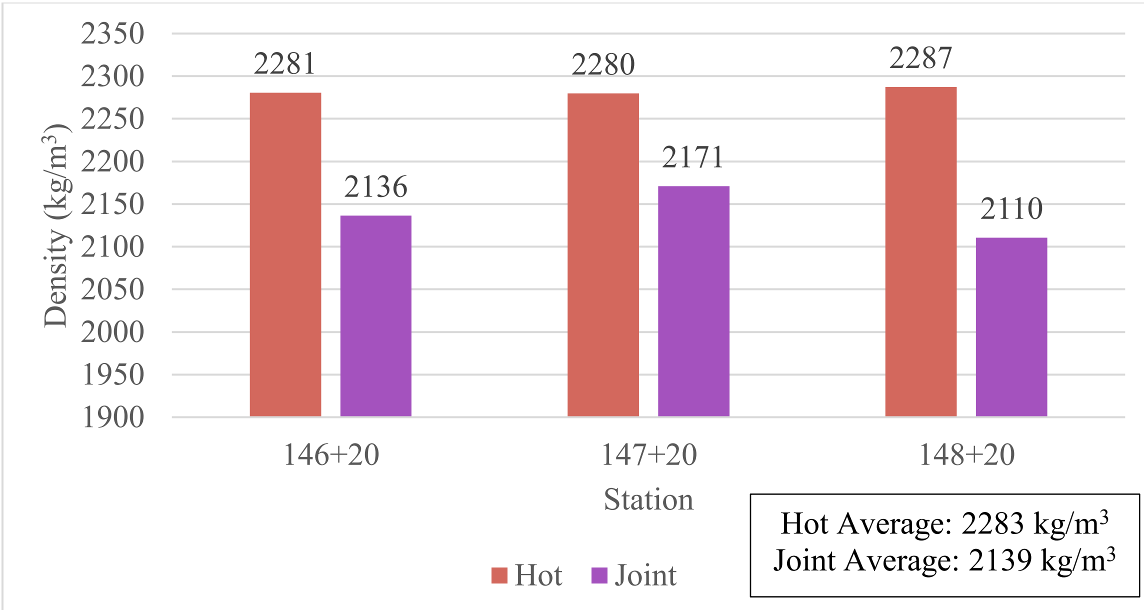

Figure 5.19: US 25 project lab density measurement

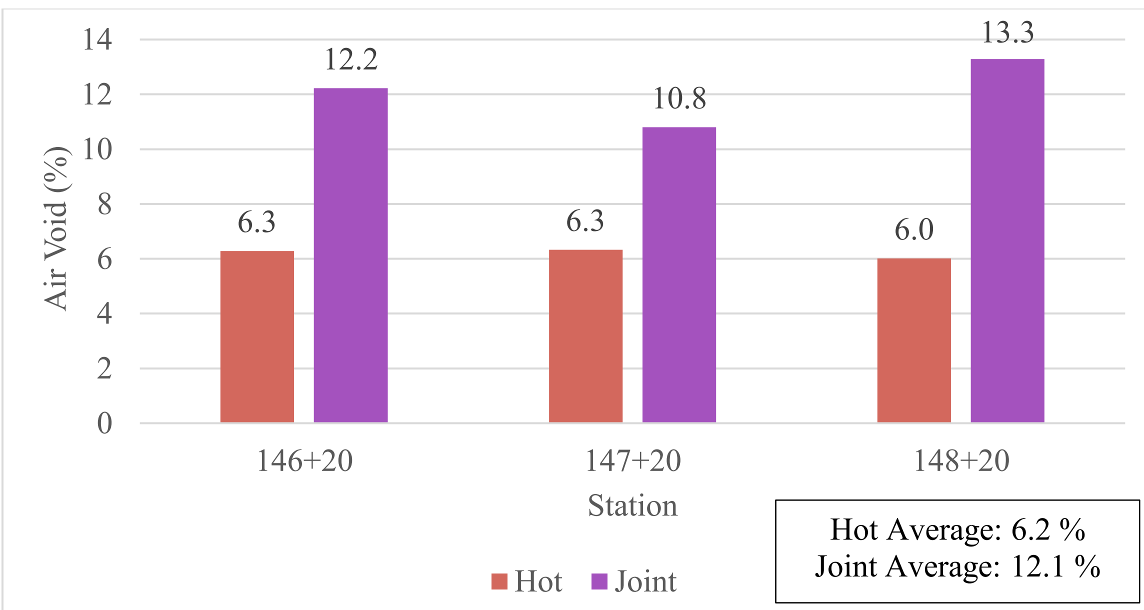

Figure 5.20: US 25 project air void contents

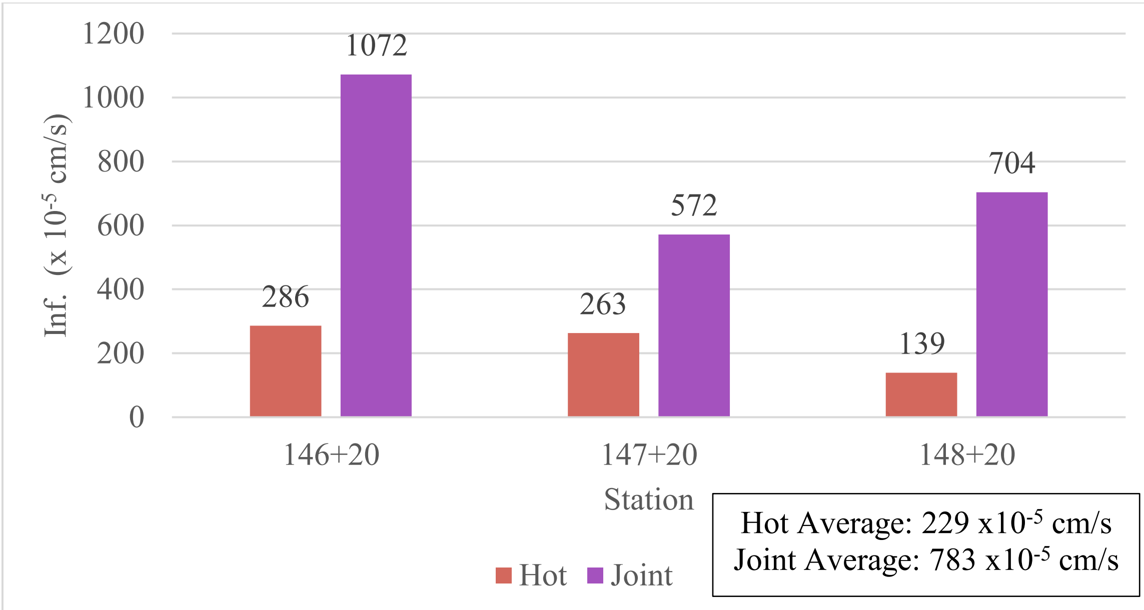

Figure 5.21: US 25 project in-place infiltration measurement

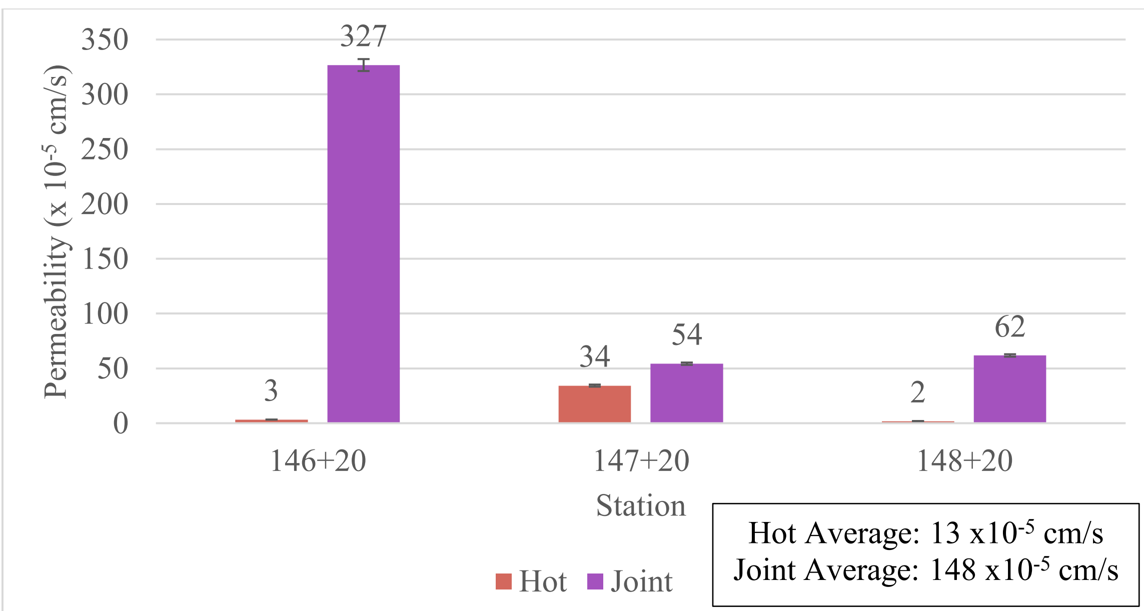

Figure 5.22: US 25 project lab permeability

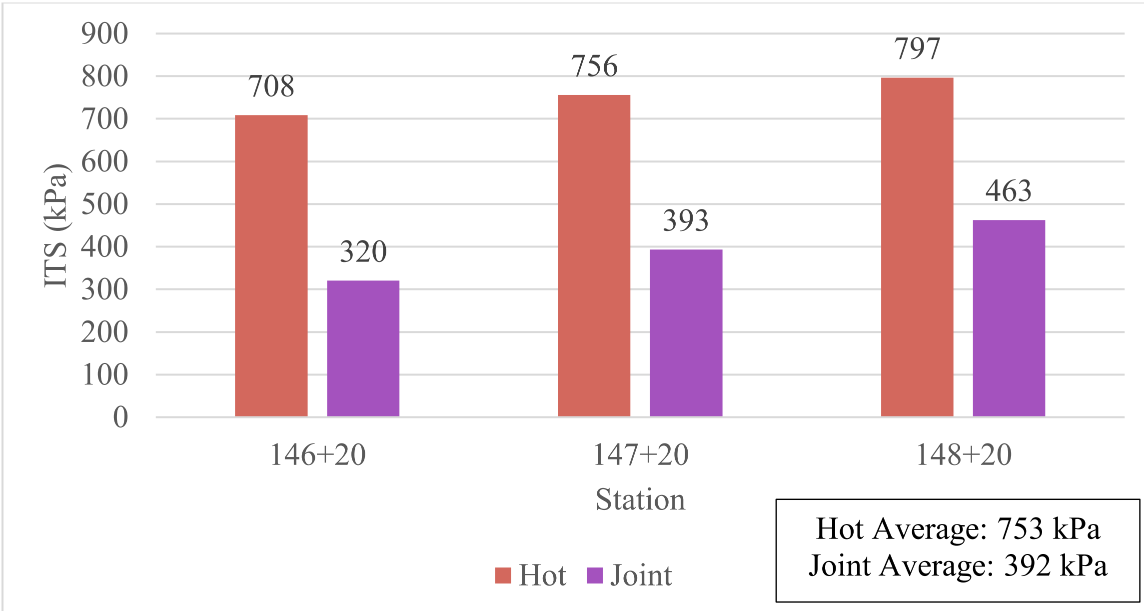

Figure 5.23: US 25 project dry indirect tensile strength (ITS) measurement

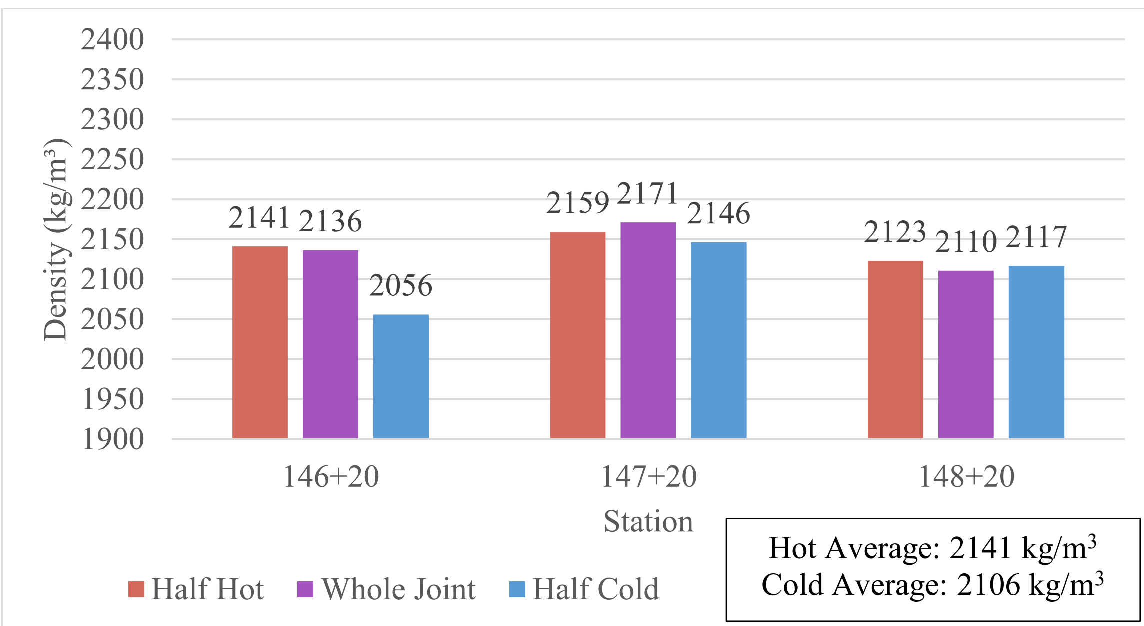

Figure 5.24: US 25 half cores lab density from the joint cores

Figure 5.6: Summary of US 25 project

(H = hot lane or half hot, J = joint, C = half cold, N/A = limited data)

Average	Hot	Joint	Cold	Significant Difference
Field Density (kg/m³)	2250	2191	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	229	783	.	No (H vs J)
Lab Density (kg/m³)	2283	2139	.	Yes (H vs J)
Lab Air Void (%)	6.2	12.1	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	13	148	.	No (H vs J)
ITS (kPa)	753	392	.	Yes (H vs J)
Half Lab Density (kg/m³)	2141	.	2106	No (H vs C)

Out of all the asphalt resurfacing projects, this was the only project with statistical differences ($\alpha = 0.05$) between the hot lane and the joint for field density and it is important to note that this project is the only project measured using the nuclear density gauge. The sensitivity of a nuclear density gauge may be greater than the non-nuclear density gauge to differentiate the density differences between the joint and the interior of the mat. The lab permeability (hot lane and joint) and half lab density (half hot and half cold core) results were the only tests that did not have significant difference. The field infiltration and lab permeability at station 146+20 measured high differences between the joint and the hot lane compared to two other stations, but no other tests resembled similar results at the same station.

During resurfacing of the Highway US 25, it was observed that the plant mix was adhering to the breakdown roller during compaction due to a malfunction of the water pump to the roller’s front wheel. This could cause an uneven surface and initiate a raveling issue due to the inconsistent amount materials being compacted. There were few occasions when the main breakdown roller had to be set aside to address the issue while the plant mix was cooling before the compaction.

US 25 (2) Project

The US 25 highway was revisited to collect more data on the safety edge joint. The same information for construction, mix design, and gradation can be found in Table 5.7, but US 25(2) had a slightly different maximum specific gravity. The second day of temperature readings, in-place density, lab density, air void content, in-place infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density taken from this project is shown in Figures 5.25 through 5.32. The summary results are displayed in Table 5.8.

Table 5.7: US 25(2) project information

Construction Information	
Location	US-25 (2)
Construction Type	Safety Edge
Compaction at Joint (First Pass)	Hot Overlap
Thickness	2.5 in
Joint Straightness	Straightish
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	3.1
Target Asphalt Content (%)	5.7
Average MSG	2.440
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	90.0
4.75 mm (No. 4)	60.0
2.36 mm (No. 8)	45.0
0.60 mm (No. 30)	25.0
0.150 mm (No. 100)	8.0
0.075 mm (No. 200)	4.0

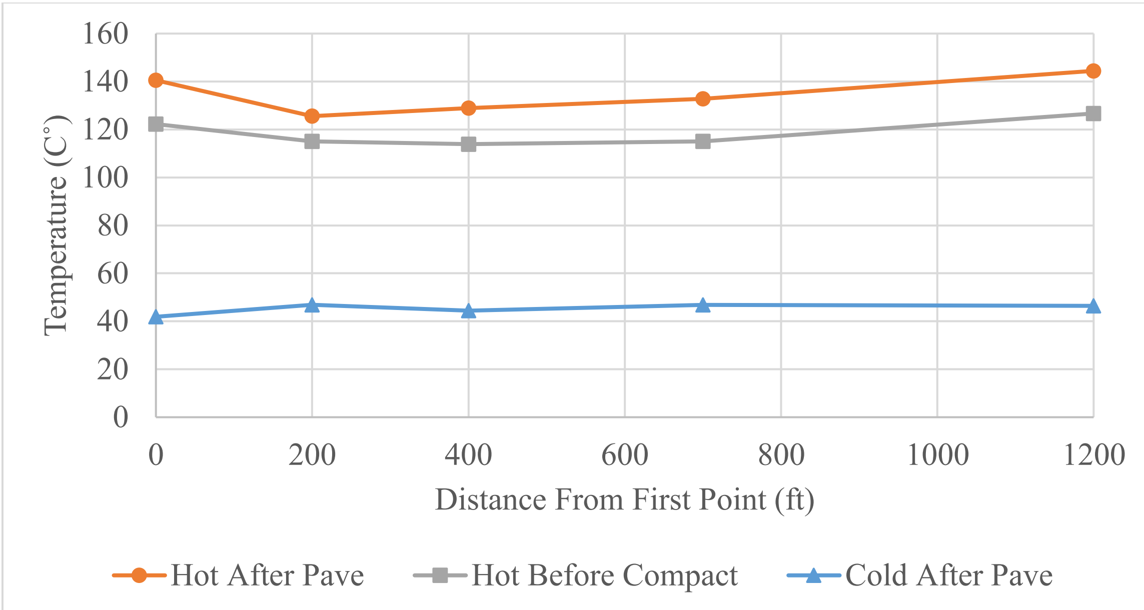

Figure 5.25: US 25(2) project pavement temperature

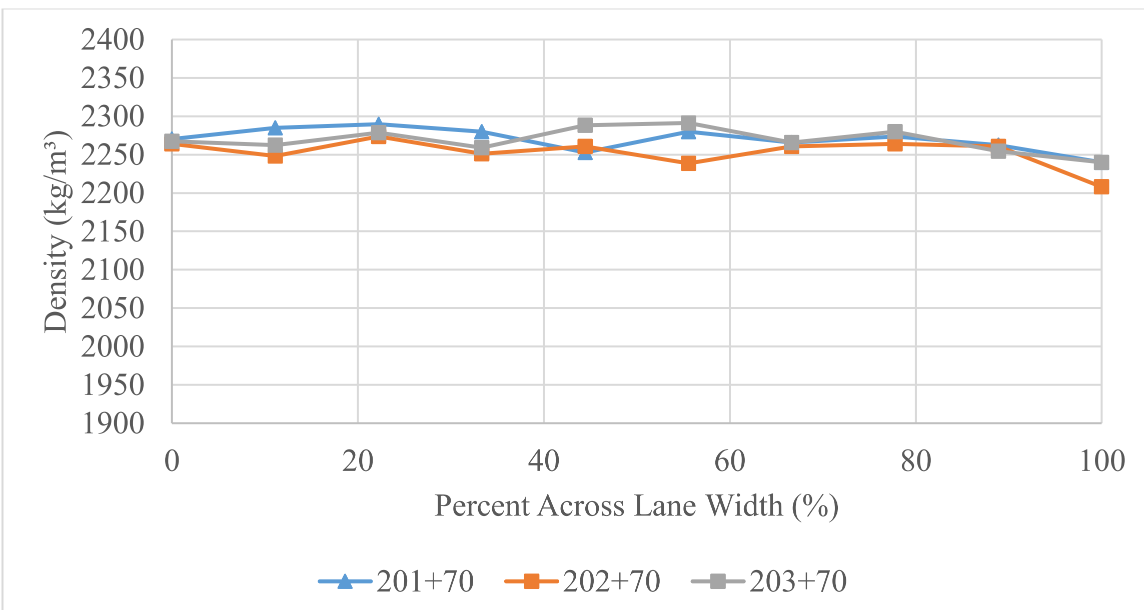

Figure 5.26: US 25(2) project in-place density measurement (measured with the PQI)

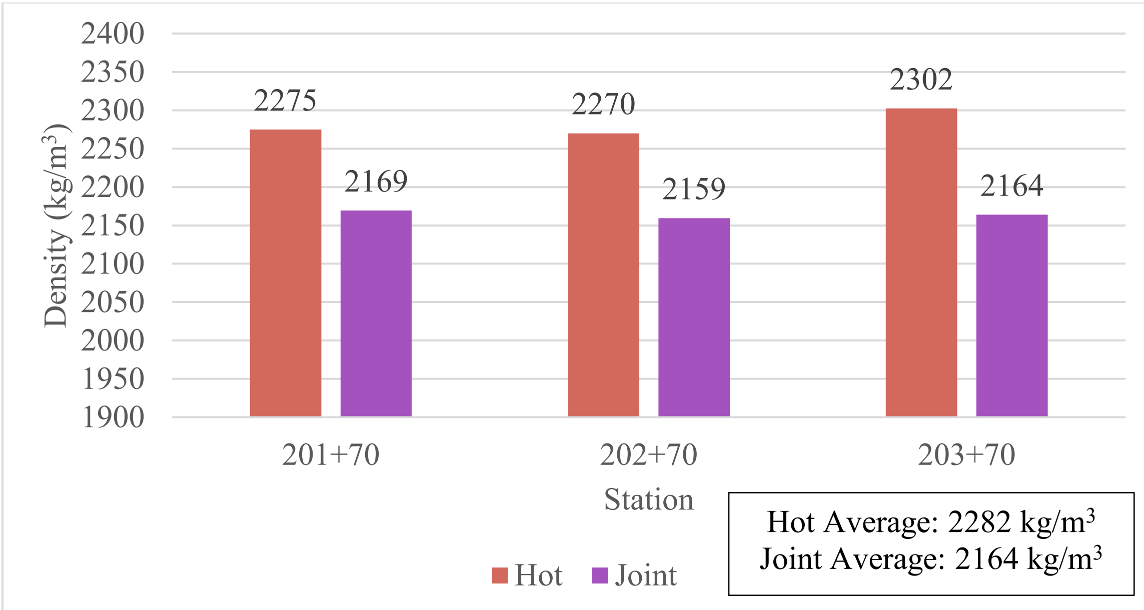

Figure 5.27: US 25(2) project lab density measurement

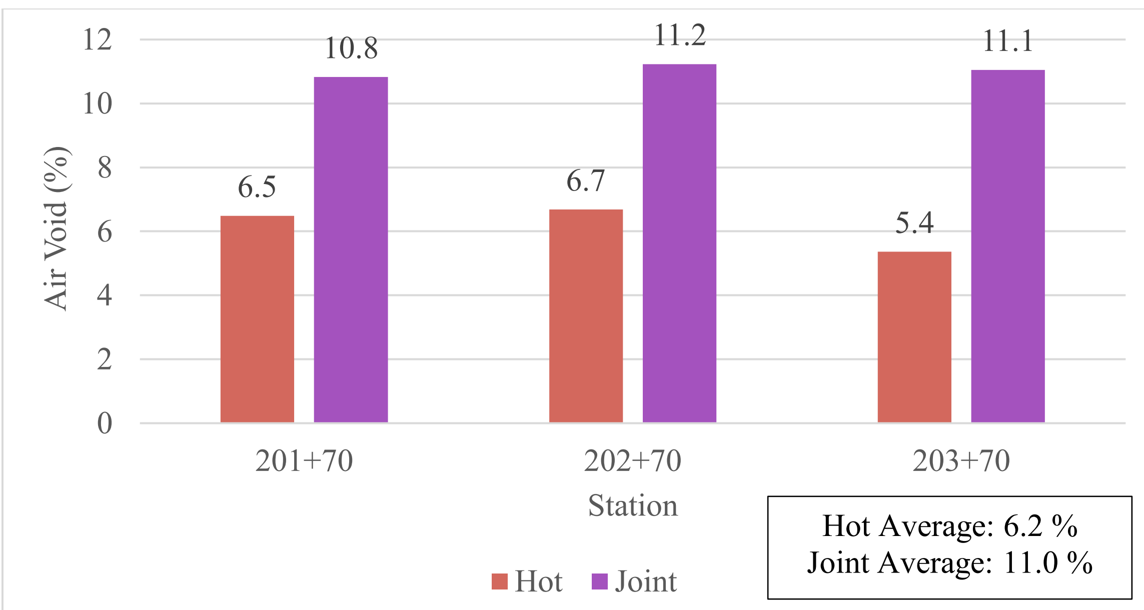

Figure 5.28: US 25(2) project air void contents

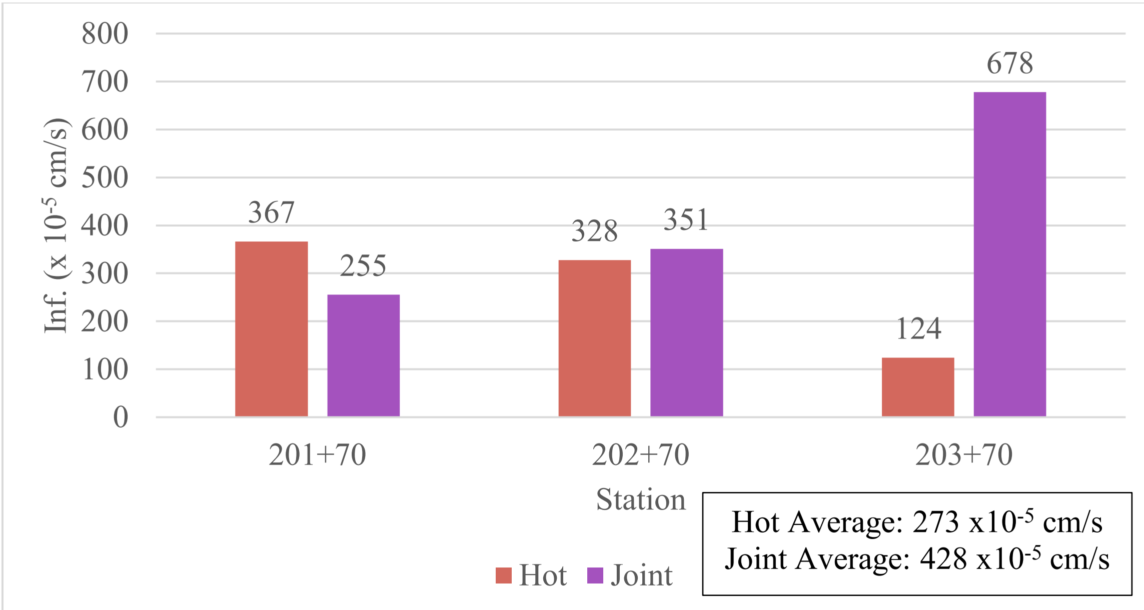

Figure 5.29: US 25(2) project in-place infiltration measurement

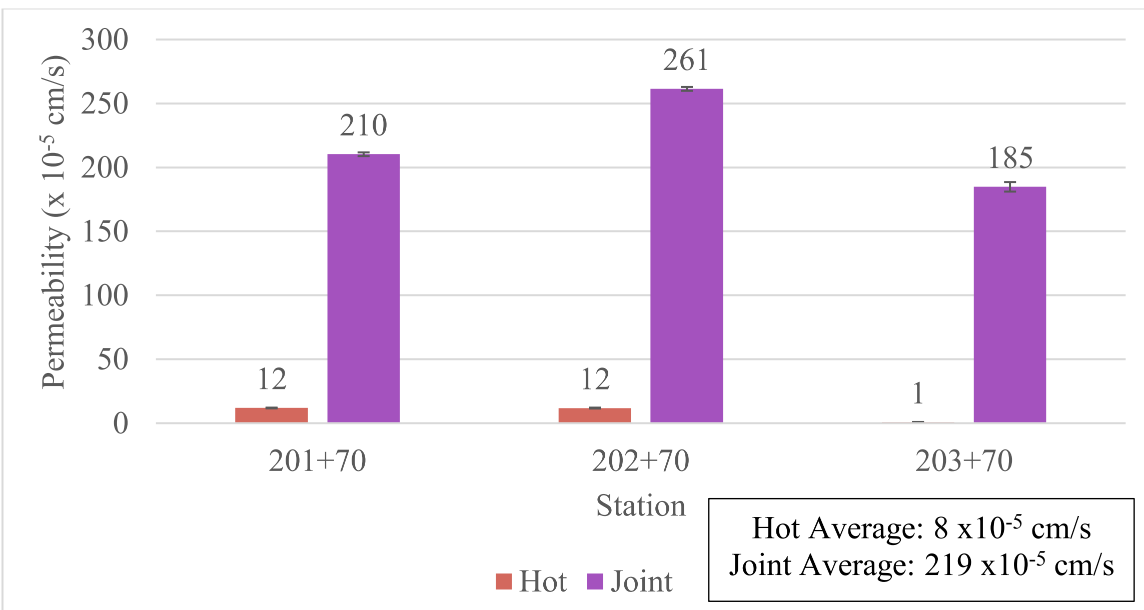

Figure 5.30: US 25(2) project lab permeability

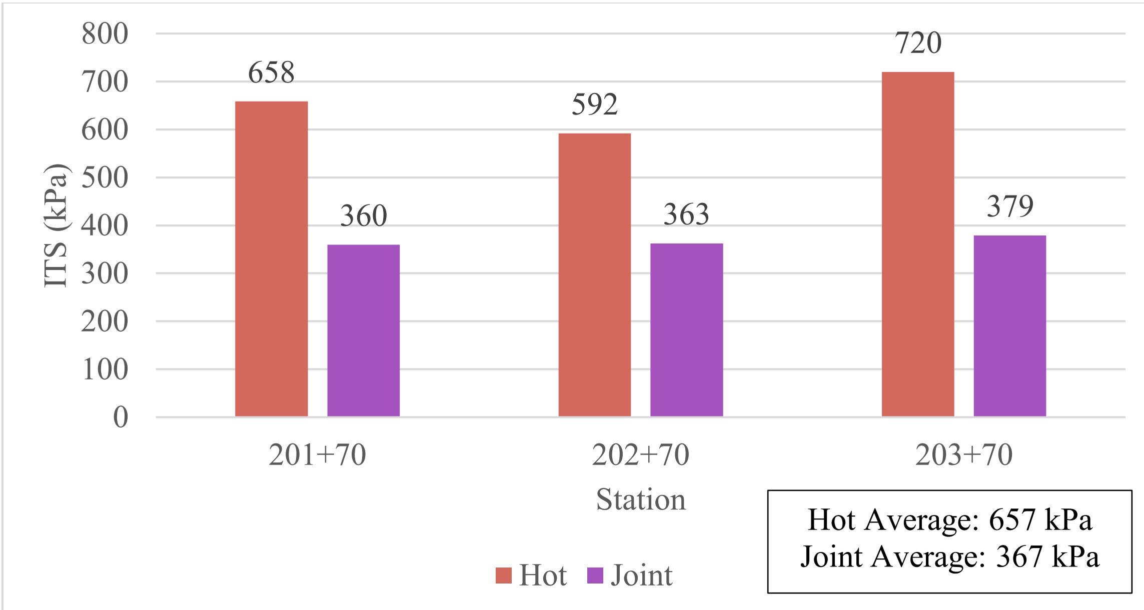

Figure 5.31: US 25(2) project dry indirect tensile strength (ITS) measurement

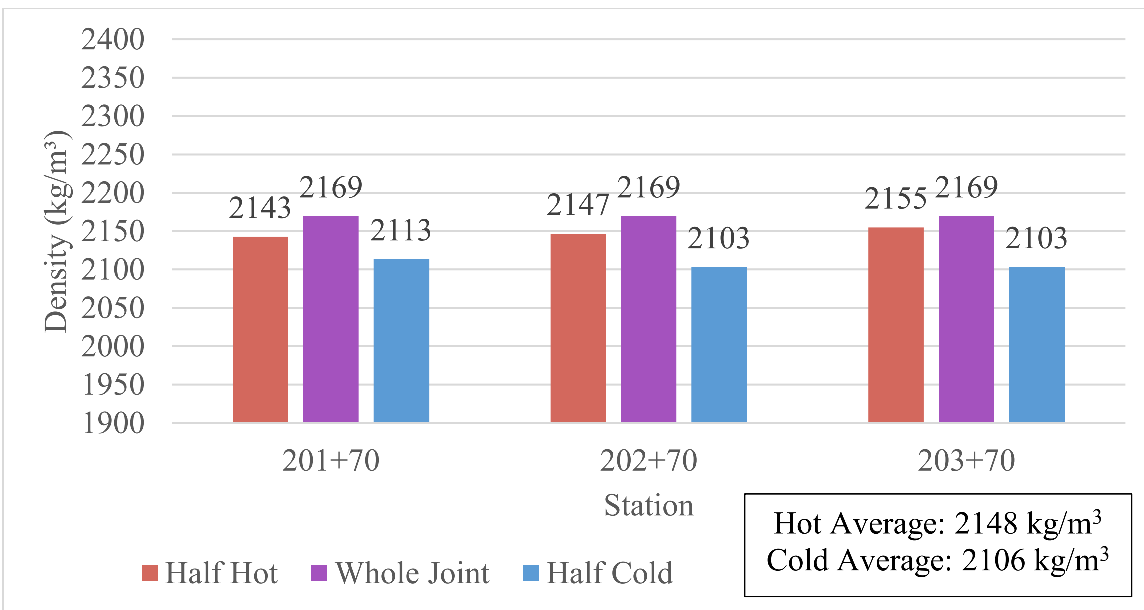

Figure 5.32: US 25(2) half cores lab density from the joint cores

Table 5.8: Summary of project US25(2)

(H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	Hot	Joint	Cold	Significant Difference
Field Density (kg/m^3)	2269	2266	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	273	428	.	No (H vs J)
Lab Density (kg/m^3)	2282	2164	.	Yes (H vs J)
Lab Air Void (%)	6.2	11.0	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	8	219	.	Yes (H vs J)
ITS (kPa)	657	367	.	Yes (H vs J)
Half Lab Density (kg/m^3)	2148	.	2106	Yes (H vs C)

For the US 25(2) project results, the lab results indicated there were significant differences between the hot lane and the joint, and half hot core and the half cold core at the joint with the significance level of 5%. Even though the US 25(2) project is the same site as the US 25 project, the results of the statistical analysis were different than the previous project in field density, field infiltration, lab density, and half lab density. For other testing, it could be explained by differences in the weather, possible change in members of the construction crew, different number of compaction passes, materials used in the mix, and other possible changes.

The vibratory breakdown roller issue, which was seen on the first visit to this project, was not witnessed on this visit. This may have improved the field density and field infiltration results compared to the first visit.

I 77 Project

Interstate 77 near Columbia, SC was overlayed with surface type A using a butt joint technique. The information on construction, mix design, and gradation is summarized in Table 5.9. Due to malfunctions of the equipment and timing of the night, the field observations could not be performed to acquire all the information needed for Table 5.9. Figures 5.33 through 5.38 display the in-place density, lab density, air void content, lab permeability, indirect tensile strength (ITS), and half core lab density results. The average values are summarized in table 5.10.

Note: Like the US 178 project, the field infiltration test could not be performed due to water leaking through seal after multiple trials.

Table 5.9: I 77 project information

Construction Information	
Location	I-77
Construction Type	Butt Joint
Compaction at Joint (First Pass)	Unknown
Thickness	2 in
Joint Straightness	Unknown
Joint Cleanness	Unknown
Joint Tack Coat	Unknown
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	Yes
Mix Design Information	
Type Mix	Surface A
AC Grade	PG 74-22
Design Air Voids (%)	2.8
Target AC (%)	5.3
Average MSG	2.439
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	97.0
9.5 mm (3/8")	84.0
4.75 mm (No. 4)	53.0
2.36 mm (No. 8)	31.0
0.60 mm (No. 30)	17.0
0.150 mm (No. 100)	8.0
0.075 mm (No. 200)	4.0

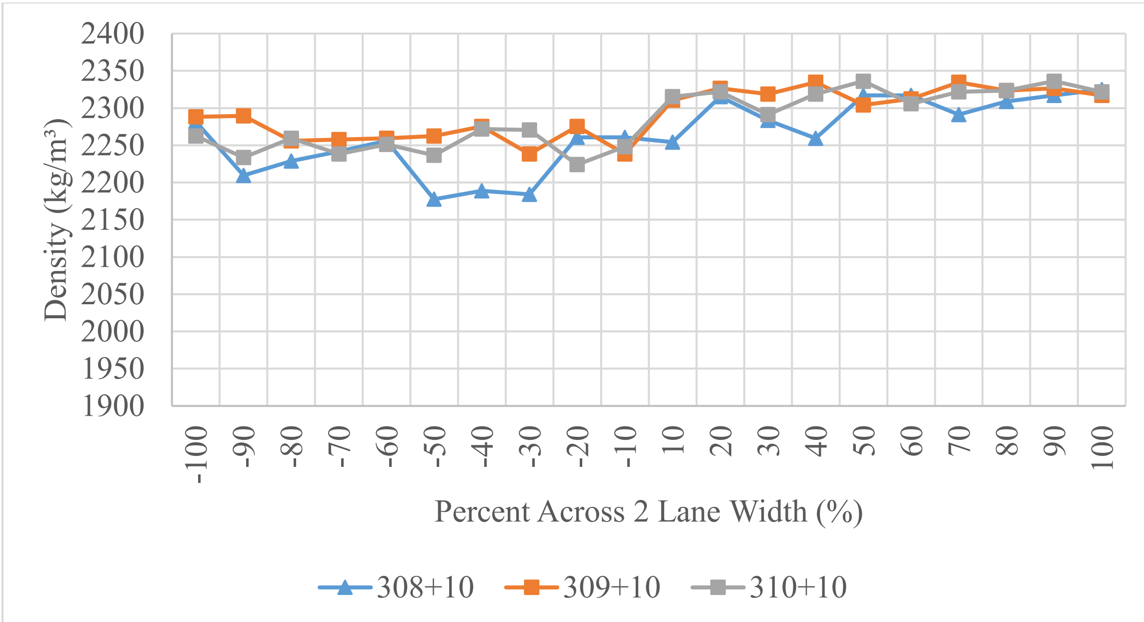

Figure 5.33: I 77 project in-place density measurement (measured with the PQI)

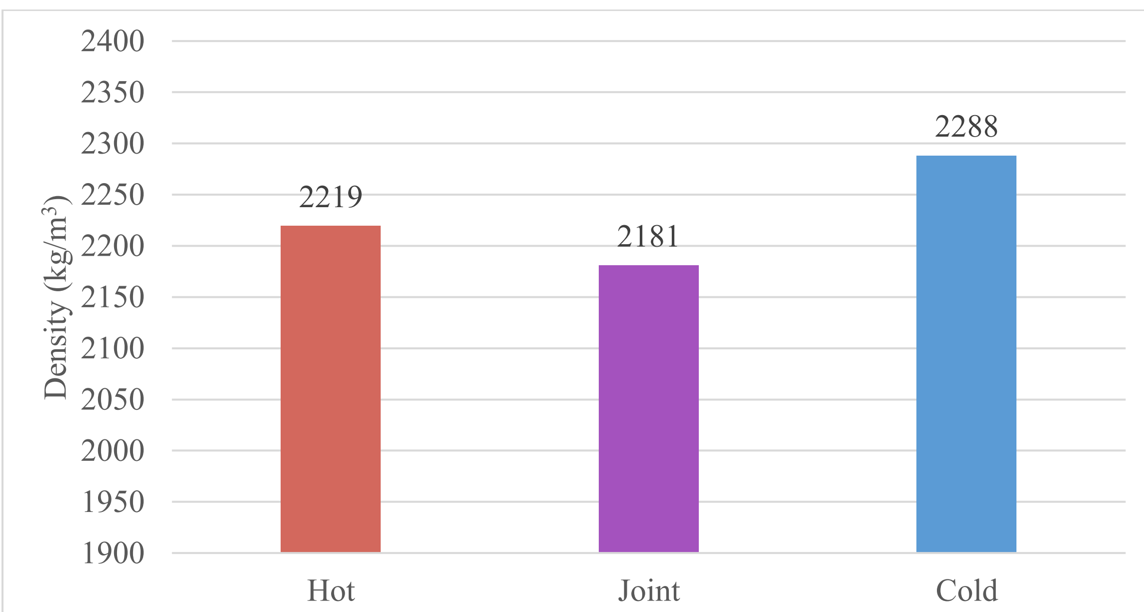

Figure 5.34: I 77 project lab density (station 308+10)

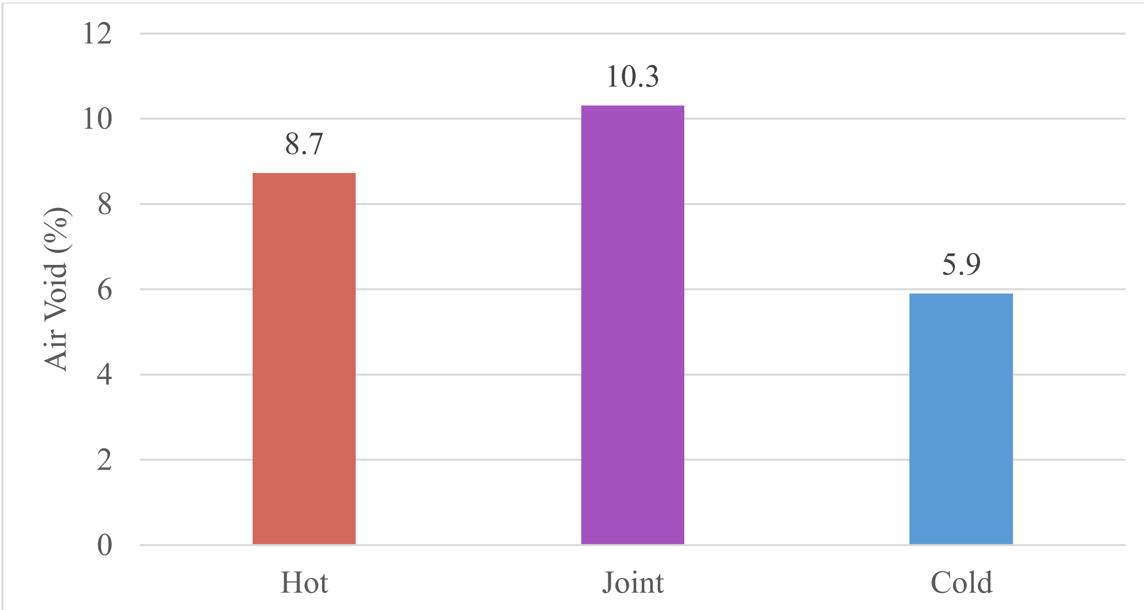

Figure 5.35: I 77 project air void contents (station 308+10)

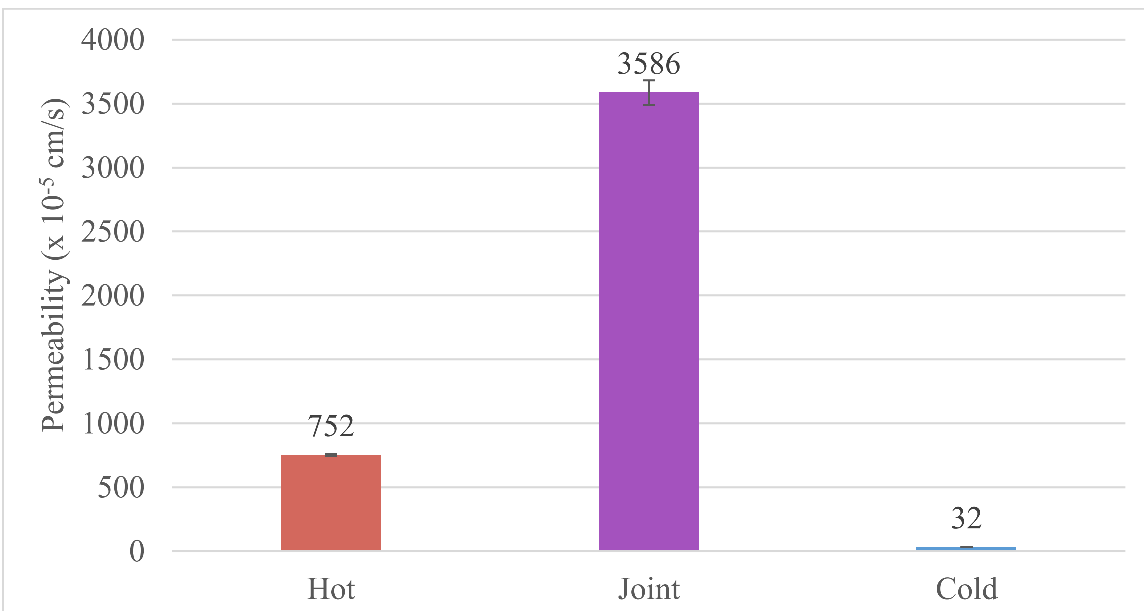

Figure 5.36: I 77 project lab permeability (station 308+10)

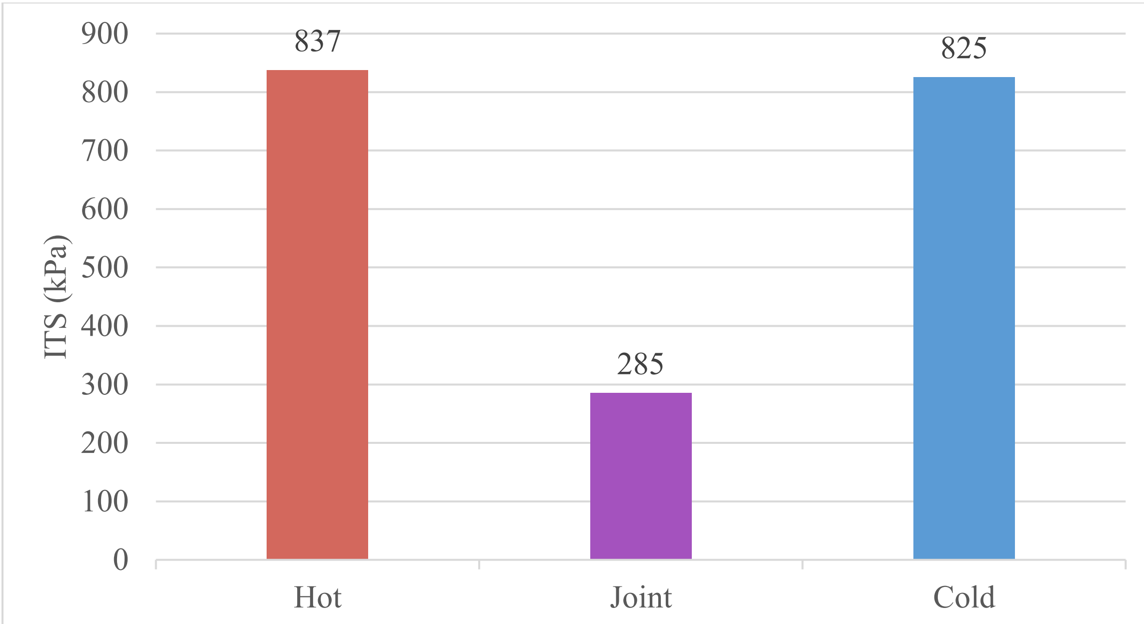

Figure 5.37: I 77 project dry indirect tensile strength (ITS) measurement (station 308+10)

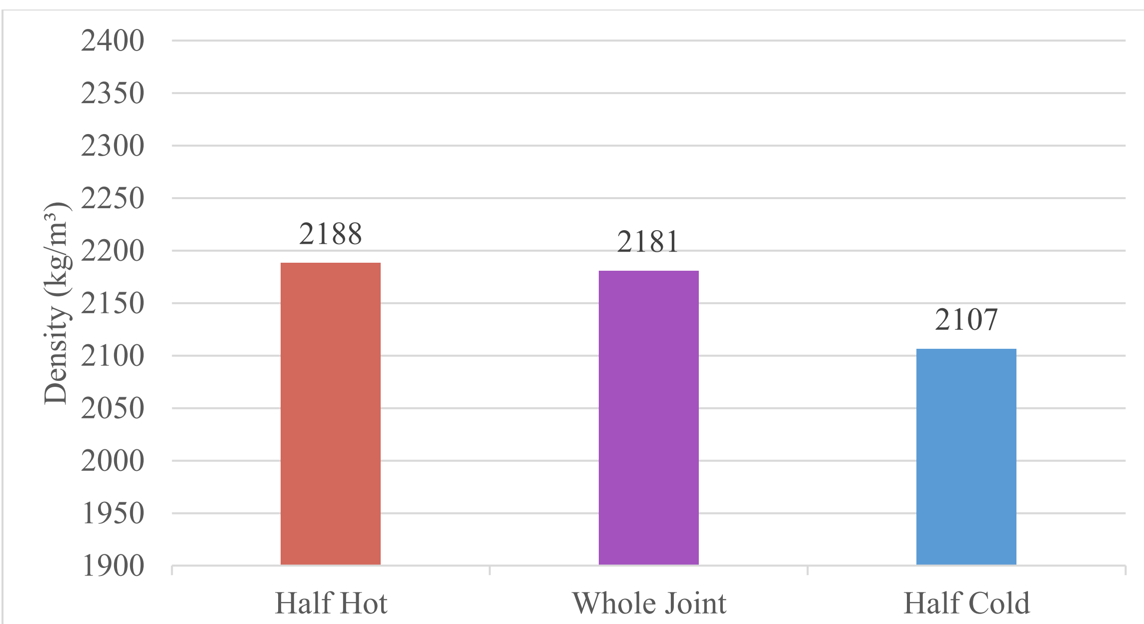

Figure 5.38: I 77 half core lab density from the joint core (station 308+10)

Table 5.10: Summary of project I-77

(H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	Hot	Joint	Cold	Significant Difference
Field Density (kg/m³)	2207	2258	2298	No (H vs J) Yes (C vs J)
Field Infiltration (x 10^{-5} cm/s)	.	.	.	N/A
Lab Density (kg/m³)	2219	2181	2288	N/A
Lab Air Void (%)	8.7	10.3	5.9	N/A
Lab Permeability (x 10^{-5} cm/s)	752	3586	32	N/A
ITS (kPa)	837	285	825	N/A
Half Lab Density (kg/m³)	2188	.	2107	N/A

For the I-77 project, cores were obtained from only one station due to the limited sample size, a statistical analysis could not be performed except for the field density. The in-place density was conducted at 3 stations that were spaced 100 ft apart and there were no significant differences found at the significance level of 5%. However, the field density difference between the cold lane and the joint was significantly different. Like previous projects, the joint had the lowest results for lab density and ITS, and the highest results for air void contents and lab permeability.

SC 8 Project

The SC 8 project was constructed using a butt joint technique and a surface type B mix was used. The construction, mix design, and gradation information can be found in Table 5.11. The graphical results for temperature readings, in-place density, lab density, air void content, in-place infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density are presented in Figures 5.39 through 5.46. The results are summarized in Table 5.12.

Note: For the SC 8 project, temperature was measured after the first roller pass due to safety reasons. The surface of the field testing and coring location was a slightly downhill grade.

Table 5.11: SC 8 project information

Construction Information	
Location	SC-8
Construction Type	Butt Joint
Compaction at Joint (First Pass)	Hot Overlap
Thickness	1.75 in
Joint Straightness	Straightish
Joint Cleanness	Loose Aggregate
Joint Tack Coat	Yes
Height of Joint	0.25 in
Material Transfer Vehicle	No
Night Time Paving	No
Mix Design Information	
Type Mix	Surface C
AC Grade	PG 64-22
Design Air Voids (%)	4.3
Target AC (%)	5.9
Average MSG	2.505
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	95.0
4.75 mm (No. 4)	69.0
2.36 mm (No. 8)	52.0
0.60 mm (No. 30)	33.0
0.150 mm (No. 100)	11.0
0.075 mm (No. 200)	5.0

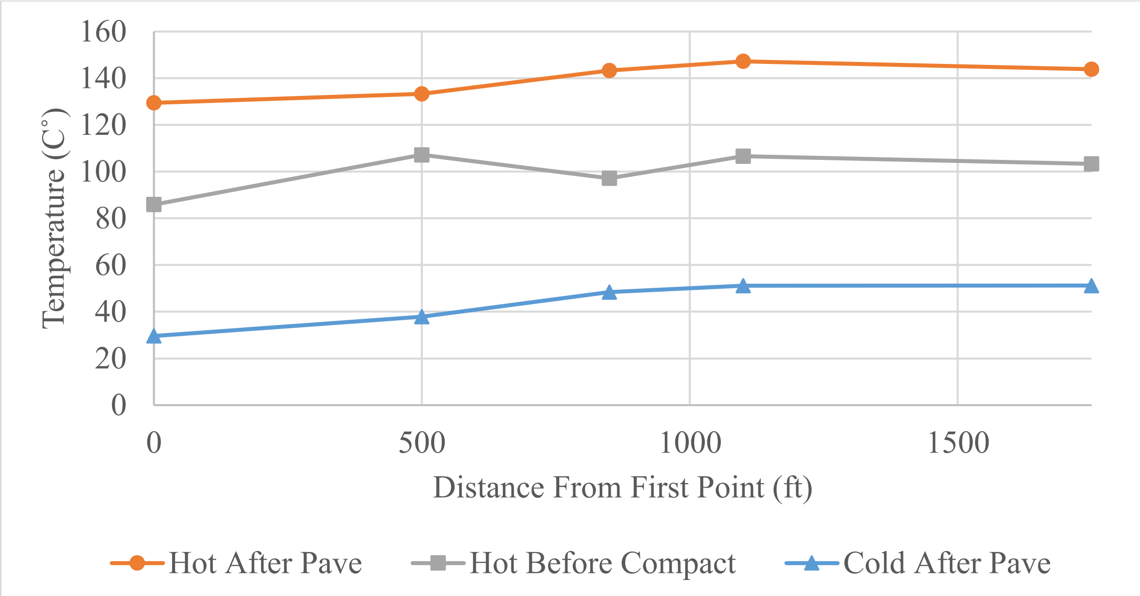

Figure 5.39: SC 8 project pavement temperature

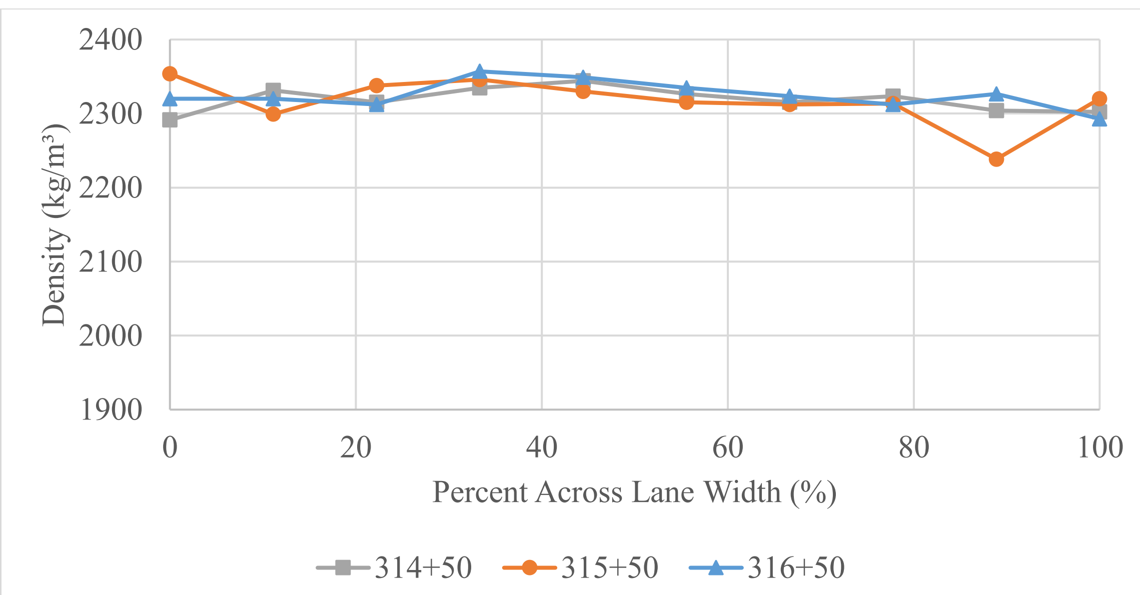

Figure 5.40: SC 8 project in-place density measurement (measured with the PQI)

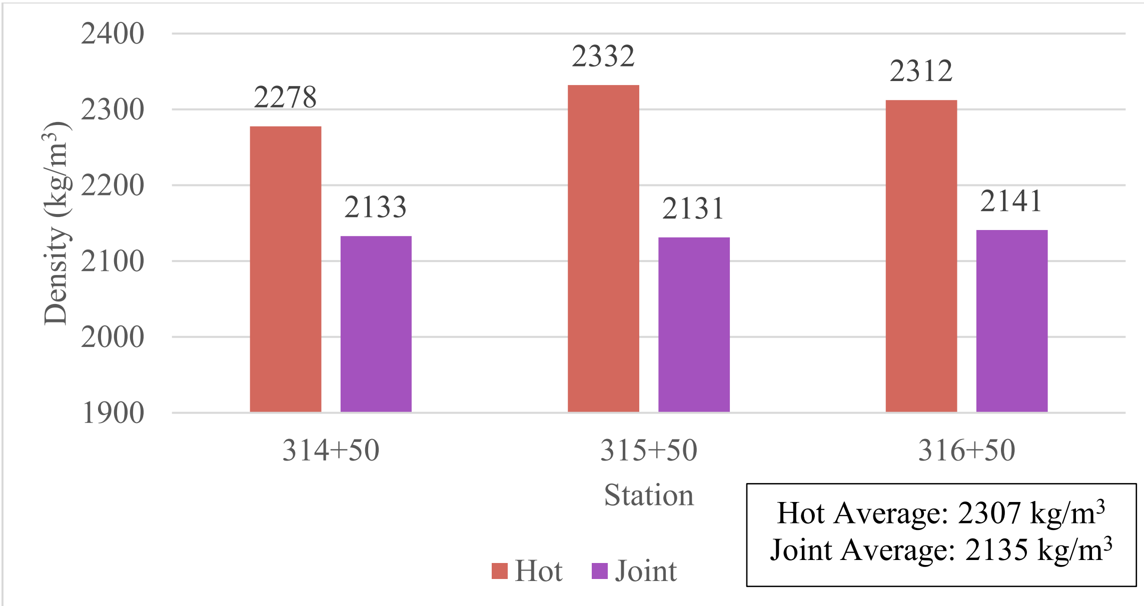

Figure 5.41: SC 8 project lab density measurement

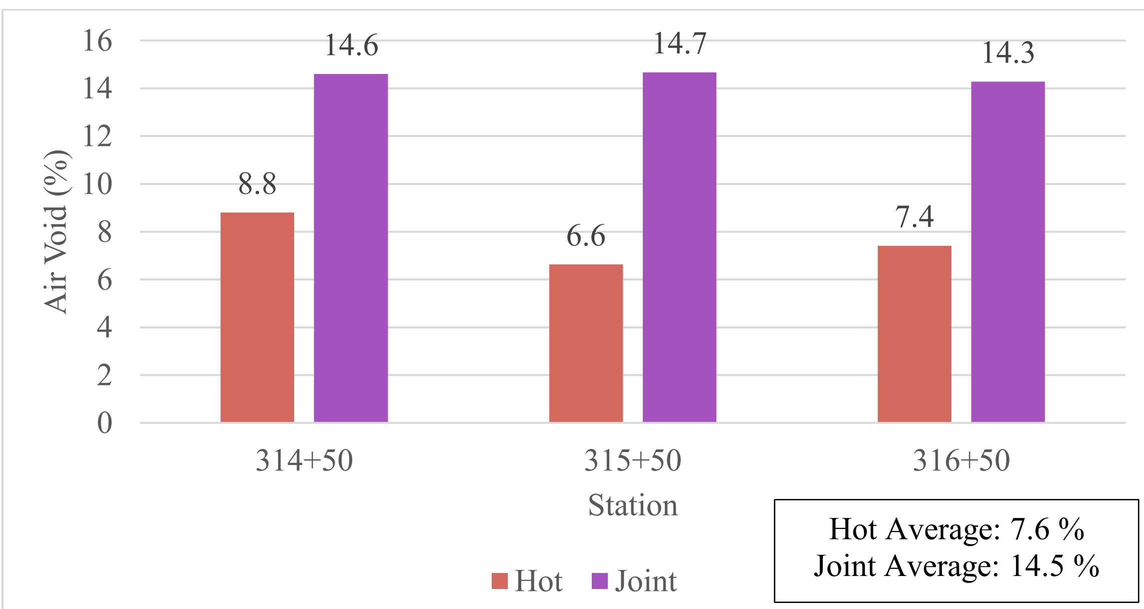

Figure 5.42: SC 8 project air void contents

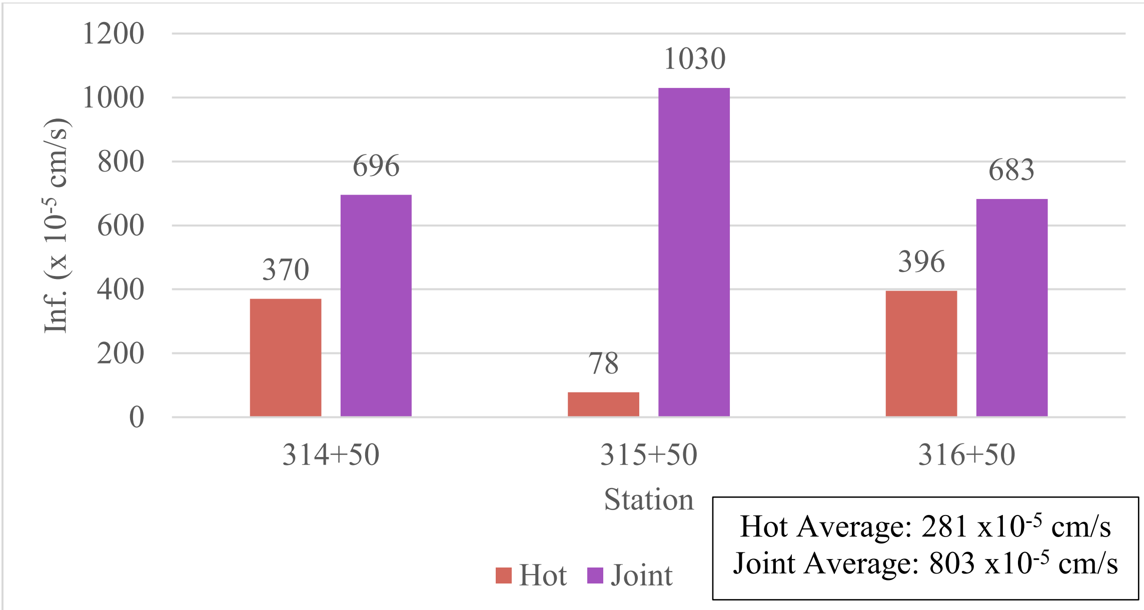

Figure 5.43: SC 8 project in-place infiltration measurement

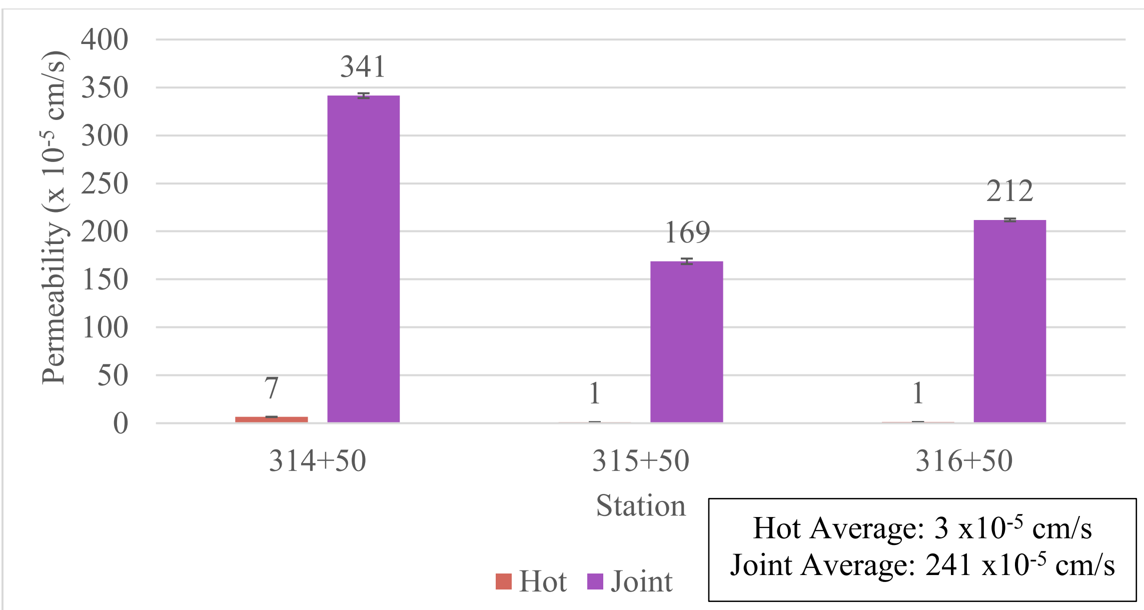

Figure 5.44: SC 8 project lab permeability

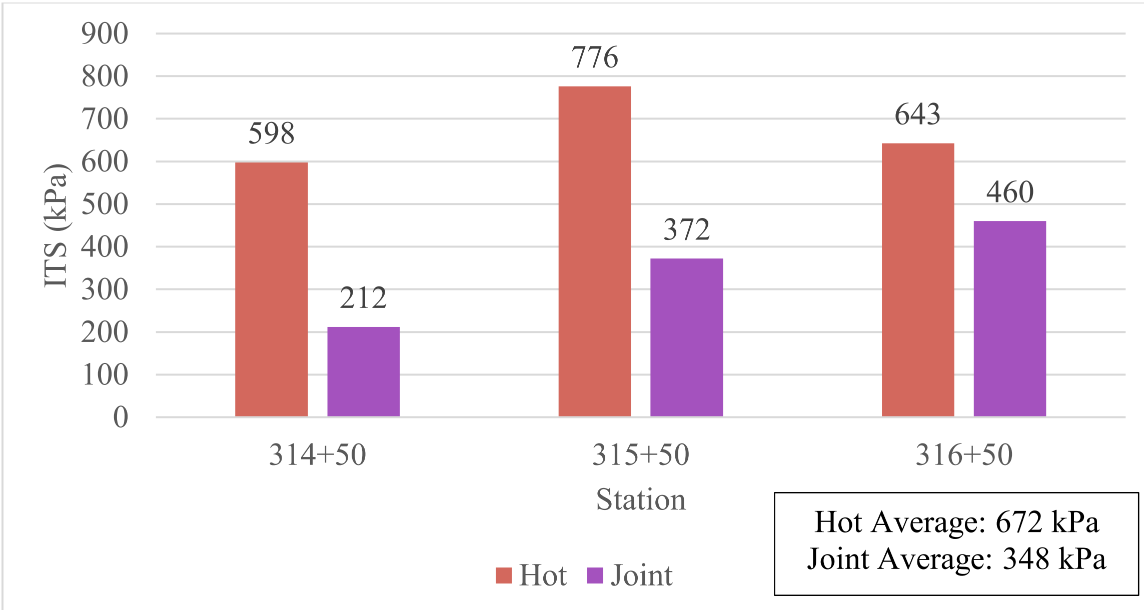

Figure 5.45: SC 8 project dry indirect tensile strength (ITS) measurement

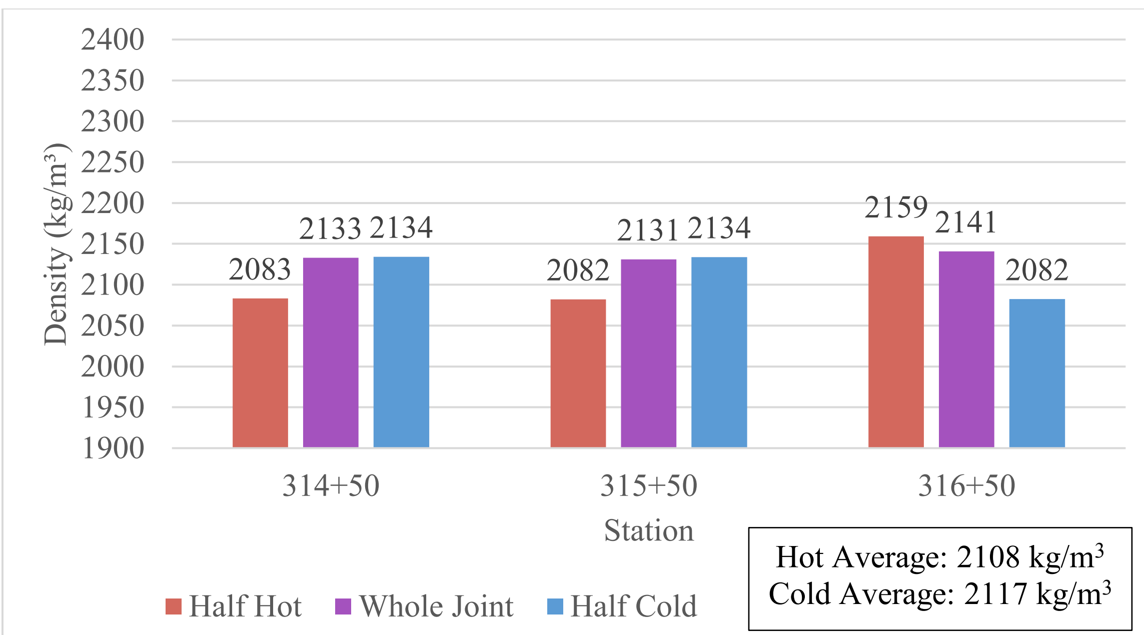

Figure 5.46: SC 8 half cores lab density from the joint cores

Table 5.12: Summary of SC 8 project

(H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2333	2319	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	281	803	.	No (H vs J)
Lab Density (kg/m³)	2307	2135	.	Yes (H vs J)
Lab Air Void (%)	7.6	14.5	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	3	241	.	Yes (H vs J)
ITS (kPa)	672	348	.	Yes (H vs J)
Half Lab Density (kg/m³)	2108	N/A	2117	No (H vs C)

The results showed that the hot lane had statistically better performance than the joint with respect to in-place infiltration, lab density, air void, lab permeability, and ITS results. The low lab density results show that the hot lane was almost impermeable, like the US 178 project. The SC 8 project followed similar trends and the performance of the joint was less than the hot lane for every metric evaluated.

This project was the only project without a material transfer vehicle (MTV) on site possibly because this was surface type C road, which will have lower traffic volumes than the surface type A and B.

S 39-57 Project

The S 39-57 project was constructed using a safety edge technique, but no compaction was conducted on the wedge. The information for construction, mix design, and gradation can be found in Table 5.13. The individual measurement of temperature, in-place density, lab density, air void content, field infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density are located in Figures 5.47 through 5.54. The results are summarized in Table 5.14.

Table 5.7: S 39-57 project information

Construction Information	
Location	S-39-57
Construction Type	Safety Edge
Compaction at Joint (First-Second)	Hot Overlap - Hot Overlap
Thickness	1.5 in
Joint Straightness	Not Straight
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	0.25 in
Extent of Joint	1.5 in
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface C
AC Grade	PG 64-22
Design Air Voids (%)	3.9
Target AC (%)	5.9
Average MSG	2.459
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.2
9.5 mm (3/8")	95.8
4.75 mm (No. 4)	67.2
2.36 mm (No. 8)	49.4
0.60 mm (No. 30)	3.4
0.150 mm (No. 100)	12.2
0.075 mm (No. 200)	5.1

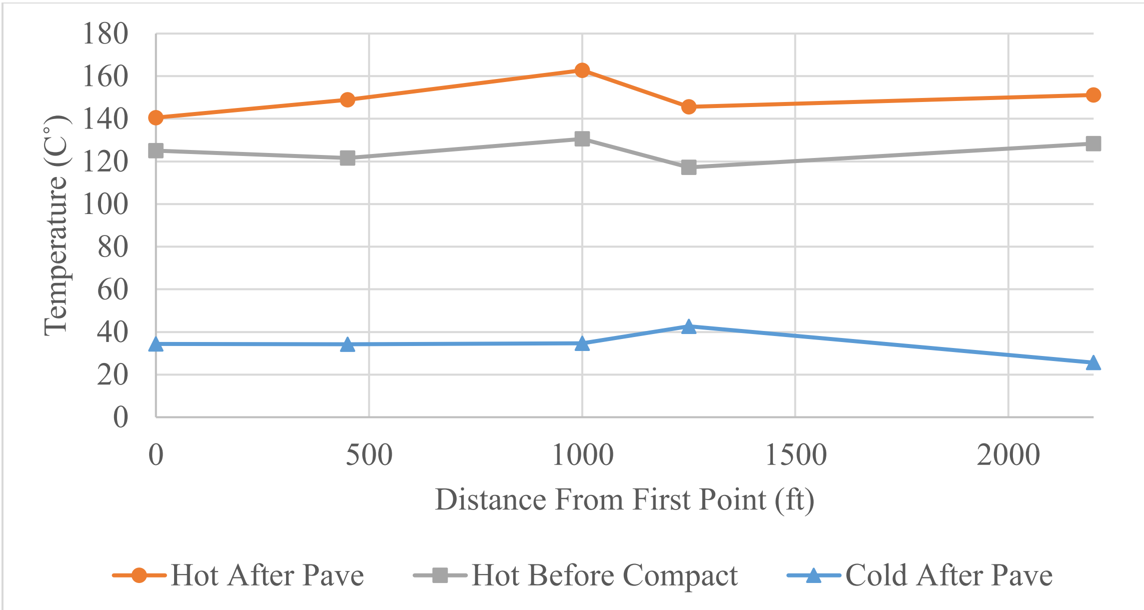

Figure 5.47: S 39-57 project pavement temperature

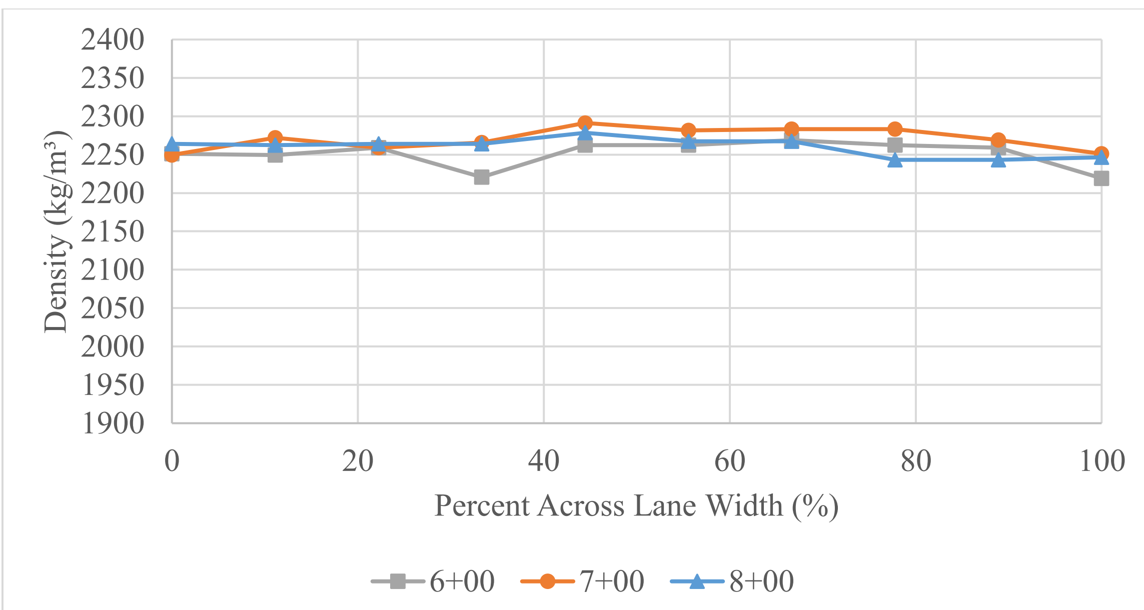

Figure 5.48: S 39-57 project in-place density measurement (measured with the PQI)

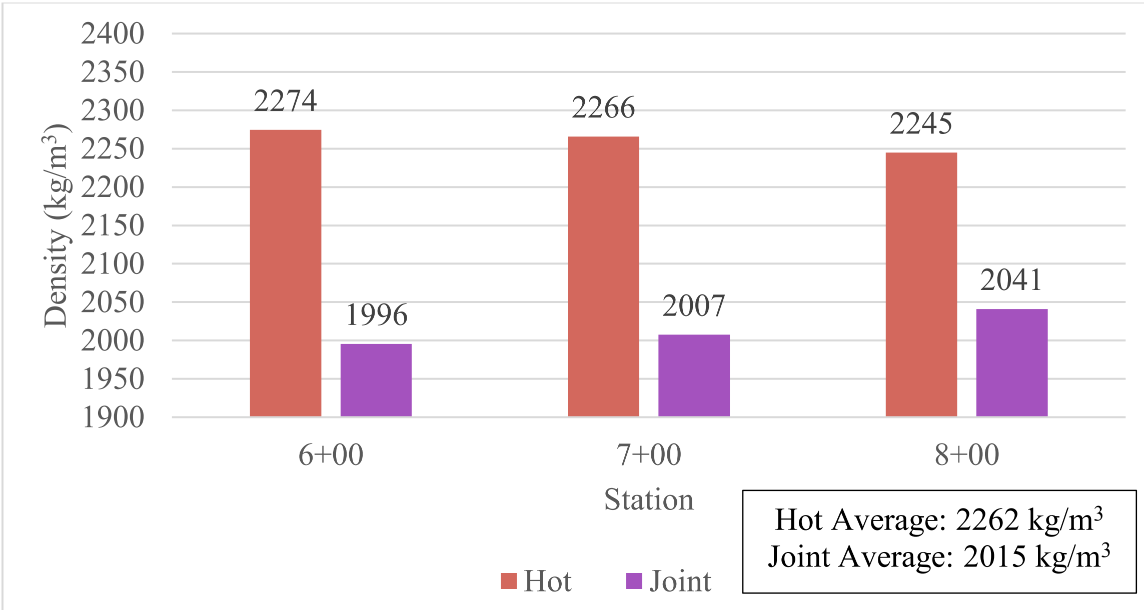

Figure 5.49: S 39-57 project lab density measurement

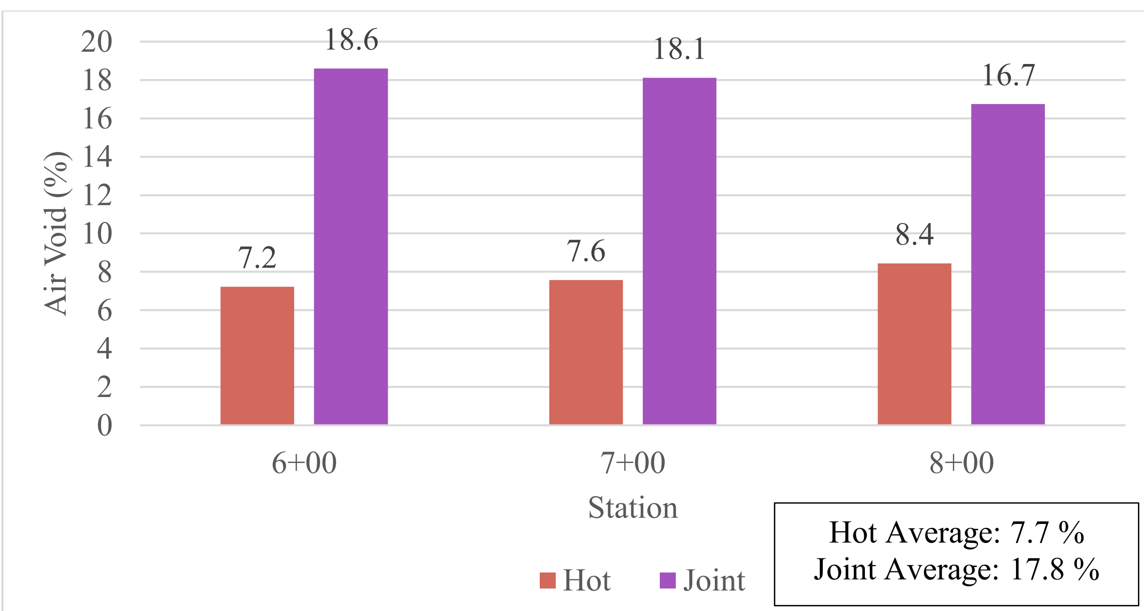

Figure 5.50: S 39-57 project air void contents

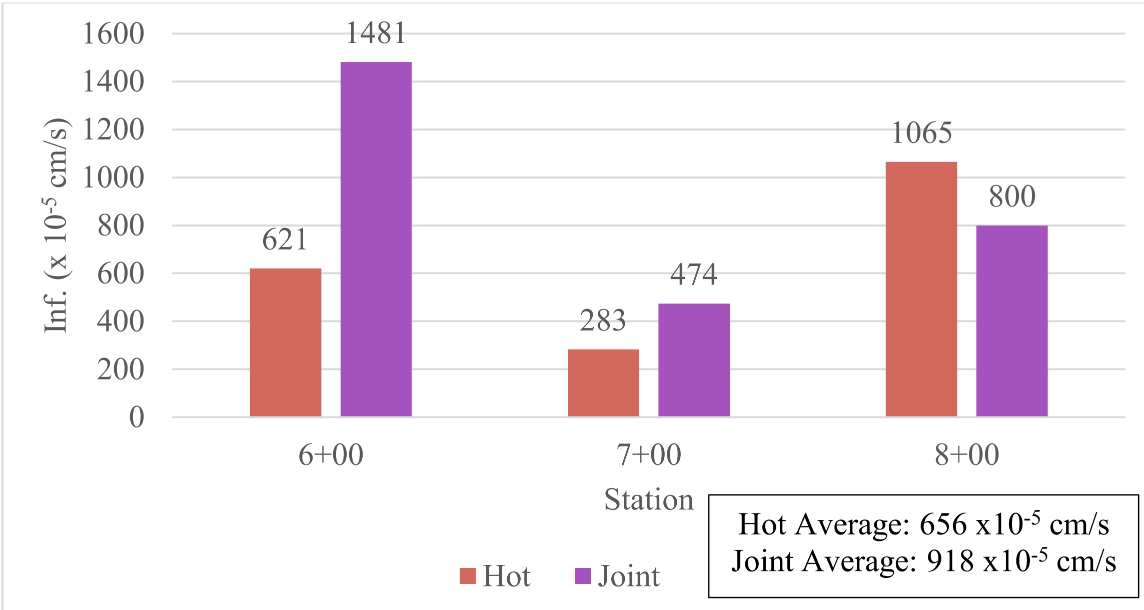

Figure 5.51: S 39-57 project in-place infiltration measurement

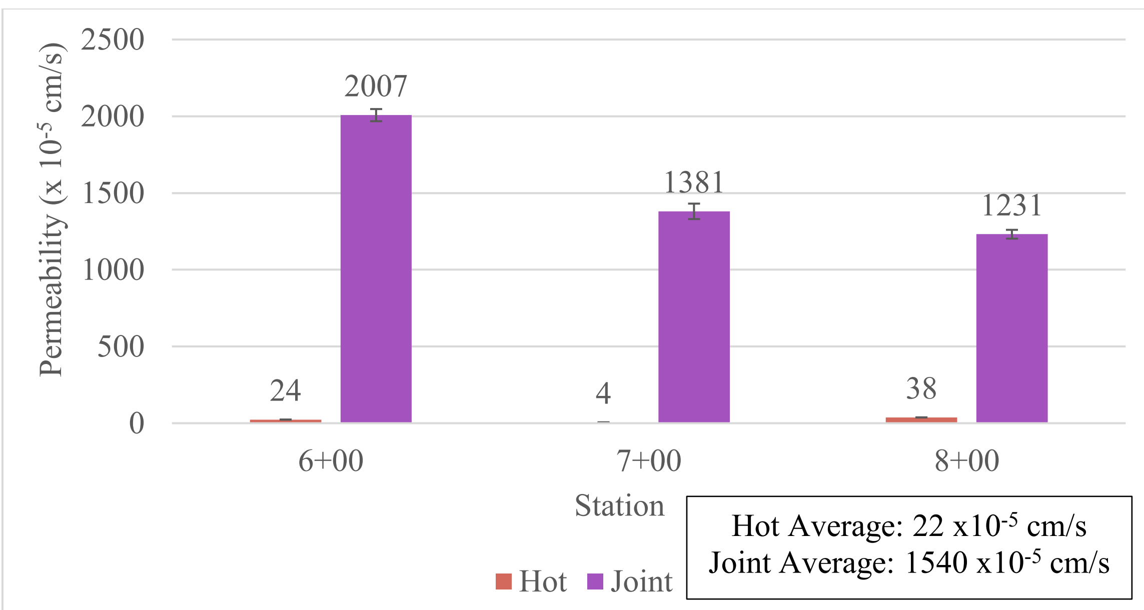

Figure 5.52: S 39-57 project lab permeability

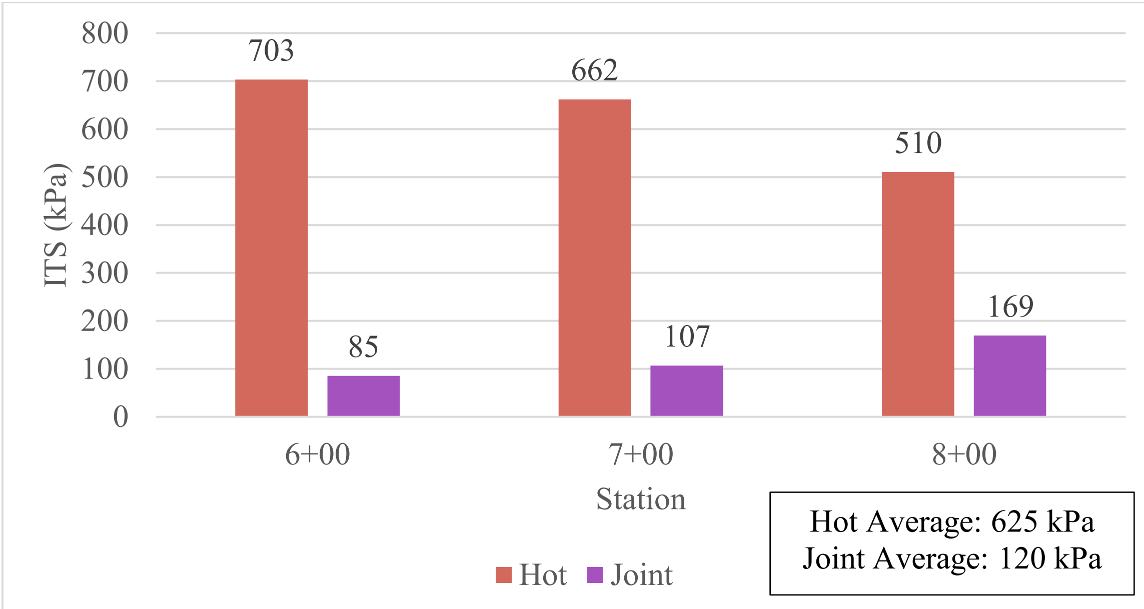

Figure 5.53: S 39-57 project dry indirect tensile strength (ITS) measurement

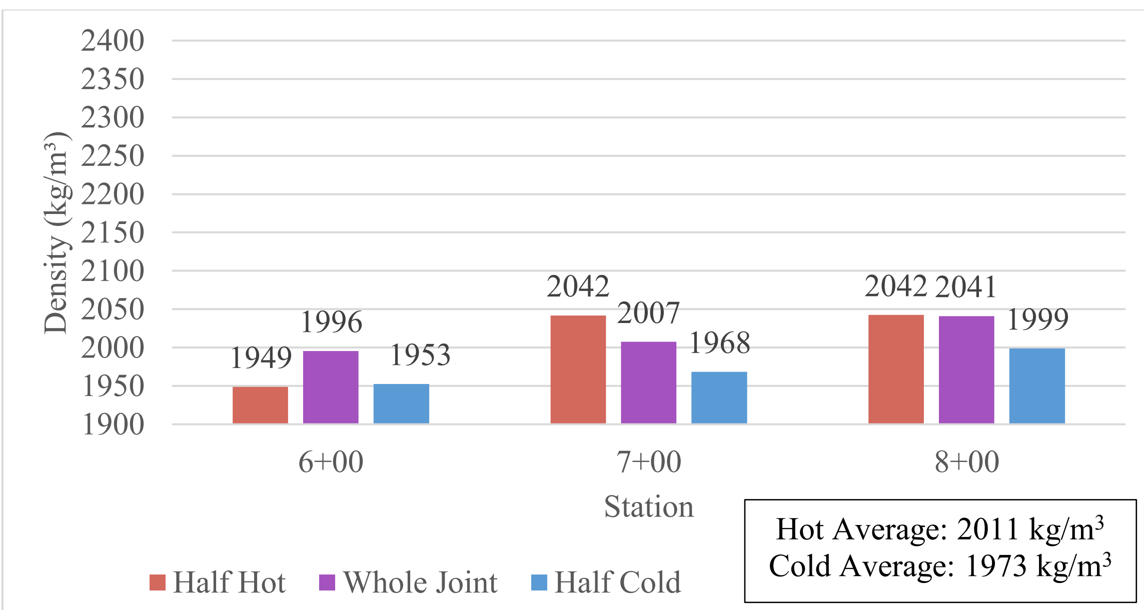

Figure 5.54: S 39-57 half cores lab density from the joint cores

Table 5.14: Summary S 39-57 project

(H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2274	2258	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	281	803	.	No (H vs J)
Lab Density (kg/m³)	2262	2015	.	Yes (H vs J)
Lab Air Void (%)	7.7	17.8	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	22	1540	.	Yes (H vs J)
ITS (kPa)	625	120	.	Yes (H vs J)
Half Lab Density (kg/m³)	2011	N/A	1973	No (H vs C)

When the S 39-57 project results for the hot lane and joint were compared, significant differences with a significance level of 5% were seen in lab density, air void, lab permeability, and ITS results. Like the previous projects, the field and lab density and ITS results were low at the joint compared to the hot lane. Additionally, as expected, the air void contents, lab permeability, and field infiltration results were high at the joint. Station 8+00 had higher in-place infiltration measurements at the hot lane compared to the joint, but no similar behavior was seen for lab permeability results at the same station.

This project had the cleanest joint out of all construction projects because the construction crew used a small motorized road sweeper to remove dirt and loose aggregates. Based on recommendations from the survey in Chapter 3, a clean joint with no loose aggregates could improve the performance of the asphalt joint.

SC 254 Project

SC 254 was a 4-lane resurfacing project that was constructed using a safety edge, but no compaction was conducted on the edge, similar to other projects. The joint was compacted with using the hot overlap method for the first pass and hot pinch for the second pass. The information for construction, mix design, and gradation are presented in Table 5.15. The temperature readings, in-place density, lab density, air void content, field infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density data taken from this project are presented in Figures 5.55 through 5.62. The results are summarized in Table 5.16.

Table 5.15: SC 254 project information

Construction Information	
Location	SC-254
Construction Type	Safety Edge
Compaction at Joint (First-Second)	Hot Overlap - Hot Pinch
Thickness	2 in
Joint Straightness	Straight
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	0.25 in
Extent of Joint	4 in
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	3.0
Target AC (%)	5.5
Average MSG	2.436
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	92.0
4.75 mm (No. 4)	60.0
2.36 mm (No. 8)	44.0
0.60 mm (No. 30)	25.0
0.150 mm (No. 100)	9.3
0.075 mm (No. 200)	4.7

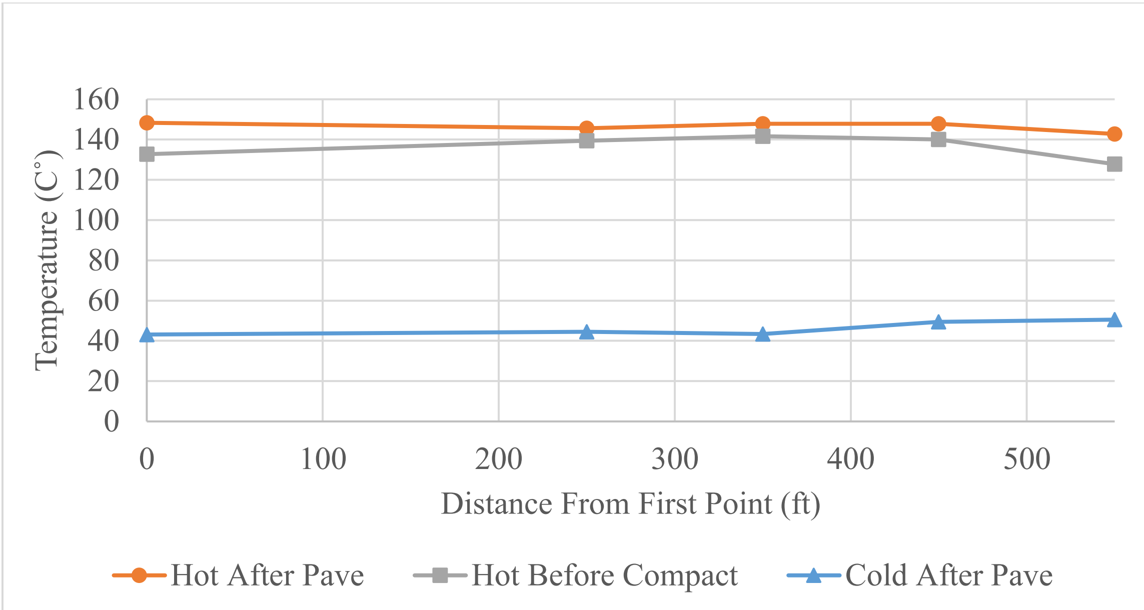

Figure 5.55: SC 254 project pavement temperature

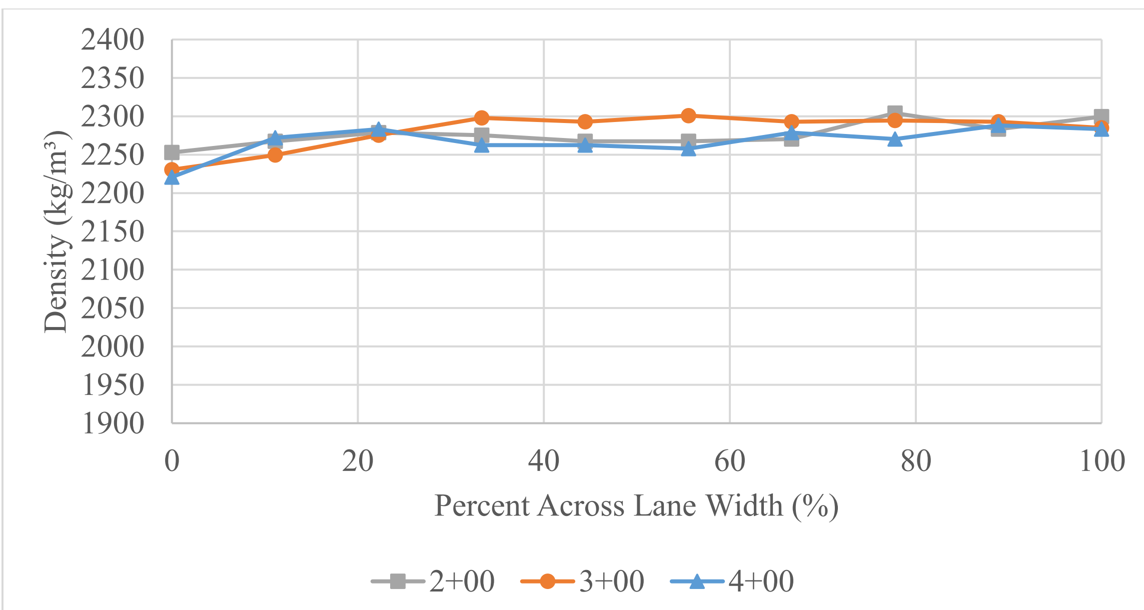

Figure 5.56: SC 254 project in-place density measurement (measured with the PQI)

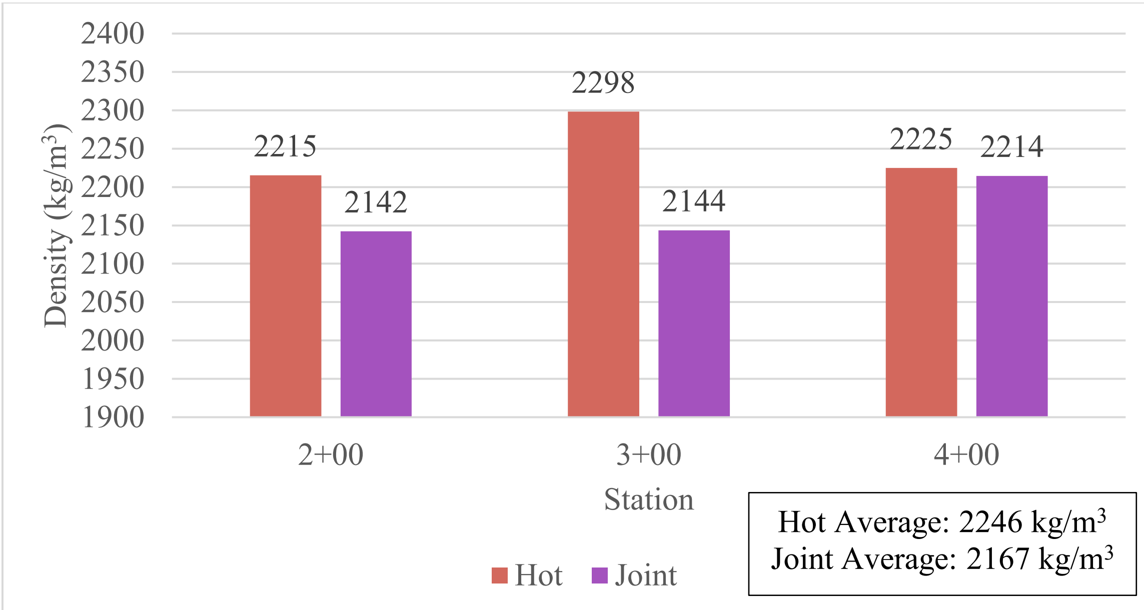

Figure 5.57: SC 254 project lab density measurement

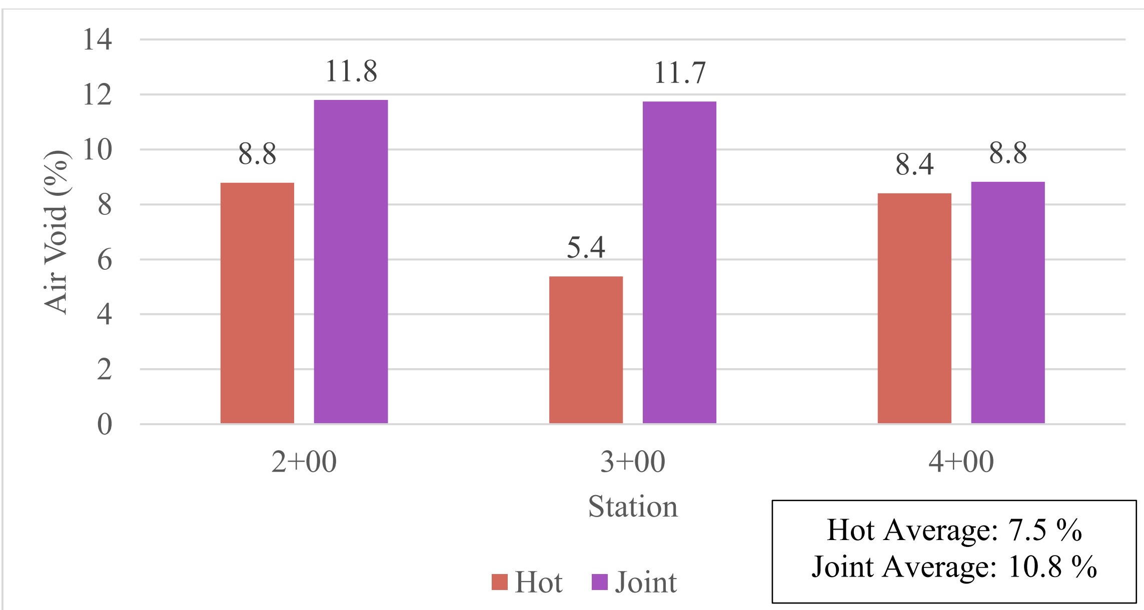

Figure 5.58: SC 254 project air void contents

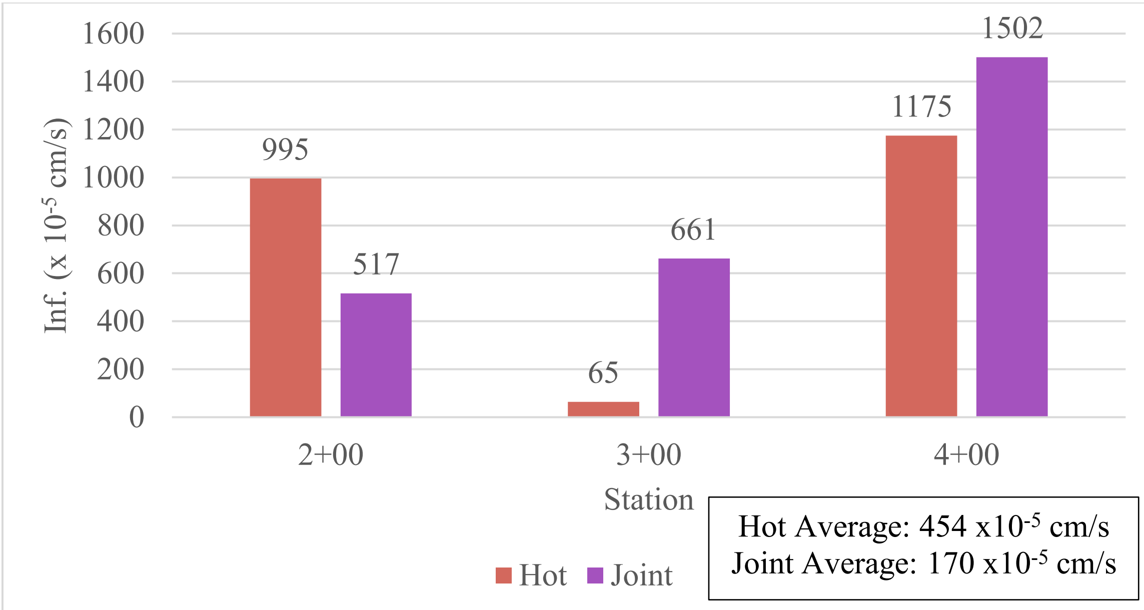

Figure 5.59: SC 254 project in-place infiltration measurement

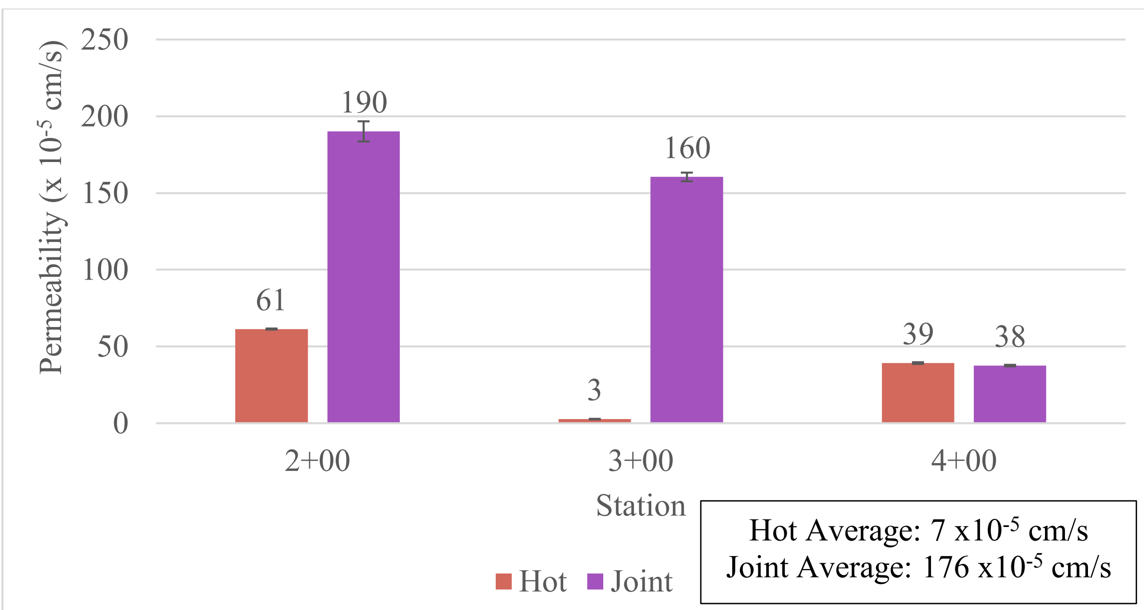

Figure 5.60: SC 254 project lab permeability

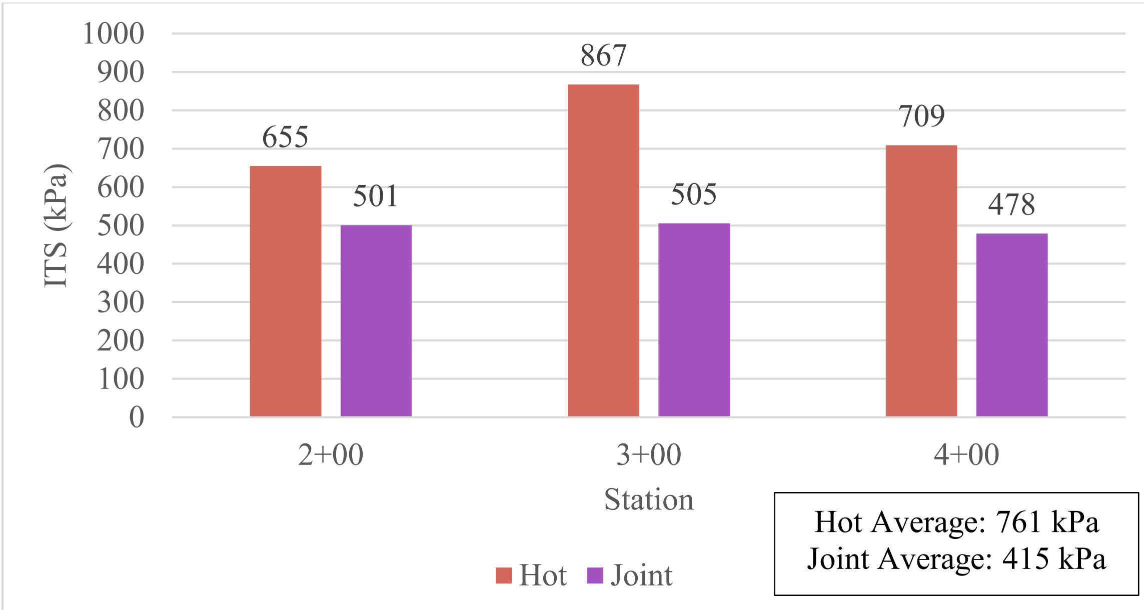

Figure 5.61: SC 254 project dry indirect tensile strength (ITS) measurement

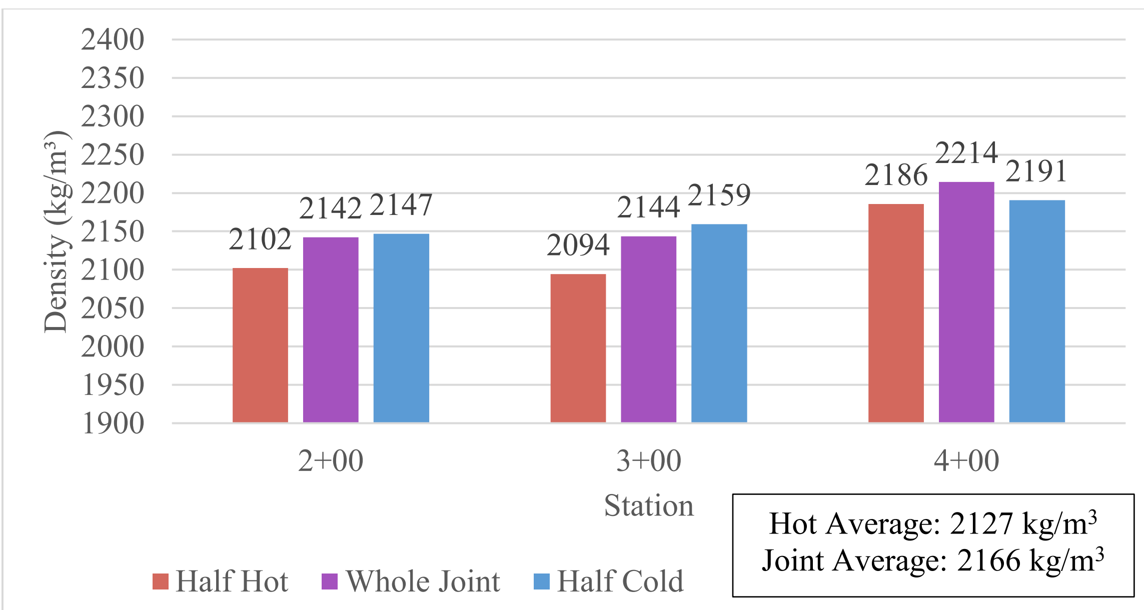

Figure 5.62: SC 254 half cores lab density from the joint cores

Table 5.16 Summary of SC 254 project

(H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m^3)	2275	2249	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	745	893	.	No (H vs J)
Lab Density (kg/m^3)	2246	2167	.	No (H vs J)
Lab Air Void (%)	7.5	10.8	.	No (H vs J)
Lab Permeability (x 10^{-5} cm/s)	34	129	.	No (H vs J)
ITS (kPa)	744	495	.	No (H vs J)
Half Lab Density (kg/m^3)	2127	.	2166	No (H vs C)

When the statistical analysis was performed for SC 254 project between the hot lane and the joint, ITS was the only result that had statistically significant result. The ITS average of 744 kPa in the interior portion of the hot lane and the ITS average of 495 kPa at the joint demonstrate that the ITS at the joint is weaker than the hot lane. Out of all asphalt resurfacing projects, all projects but SC 254 exhibited significantly different ITS results. The ITS results demonstrate the strength of adhesion between the matching lanes at the joint. The half lab density results did show significant differences between the hot side and the cold side.

SC 11 Project

Highway SC 11 was the last project visited and it was constructed with a safety edge without compaction on the edge. The joint was compacted with hot overlap method for the first and second pass at the joint. The mix design and aggregate gradation information can be found in Table 5.17. Due to the heavy traffic, the cold lane temperature could not be measured. The temperature readings, lab and field density, air void contents, field infiltration, lab permeability, ITS, and half core density are found in Figure 5.63 through 5.70. The results are summarized in Table 5.18.

Note: The cores for the SC 11 project were taken on a slightly curved section of roads, which may influence the test results.

Table 5.17: SC 11 project information

Construction Information	
Location	SC-11
Construction Type	Safety Edge
Compaction at Joint (First-Second)	Hot Overlap - Hot Overlap
Thickness	2 in
Joint Straightness	Straightish
Joint Cleannes	Loose Aggregate
Joint Tack Coat	Yes
Height of Joint	0.25 in
Extent of Joint	1 in
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	3.8
Target AC (%)	5.9
Average MSG	2.456
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	95.0
4.75 mm (No. 4)	67.0
2.36 mm (No. 8)	50.0
0.60 mm (No. 30)	33.0
0.150 mm (No. 100)	12.0
0.075 mm (No. 200)	4.0

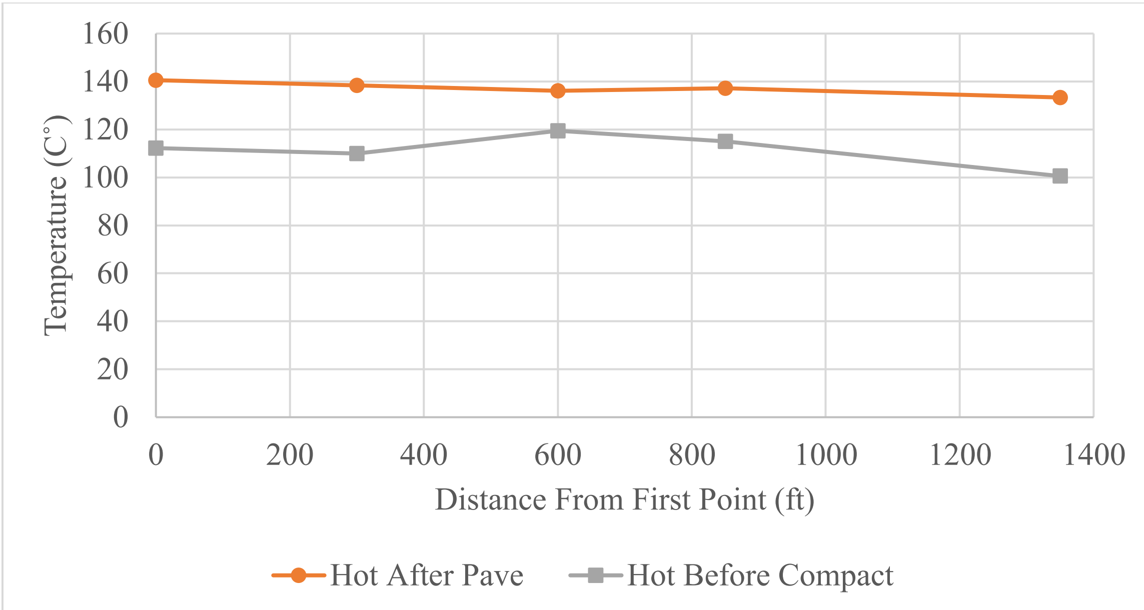

Figure 5.63: SC 11 project pavement temperature

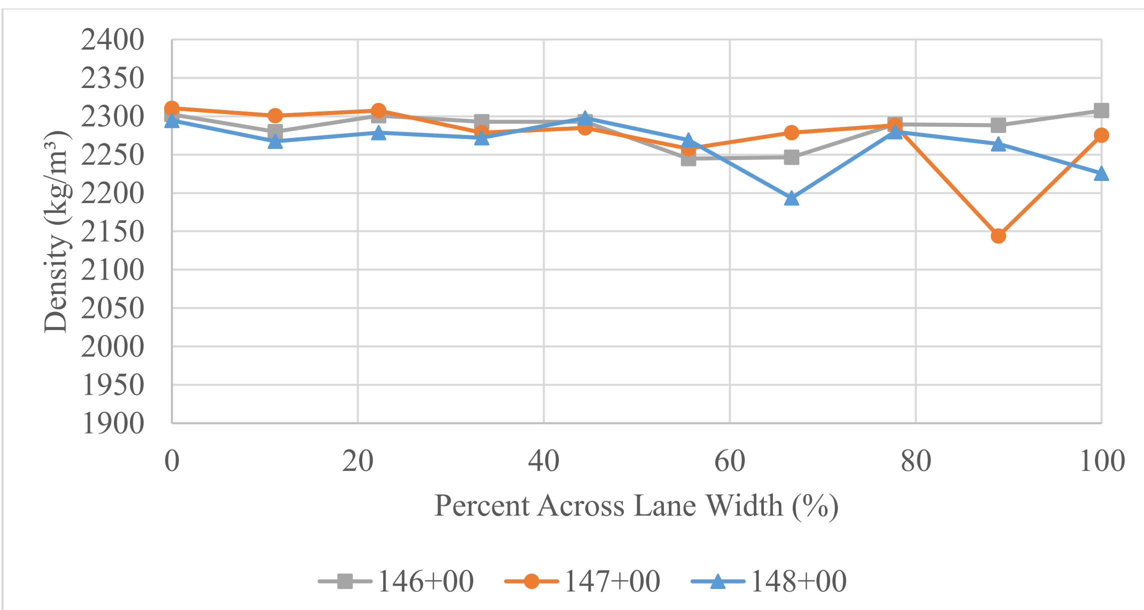

Figure 5.64: SC 11 project in-place density measurement (measured with the PQI)

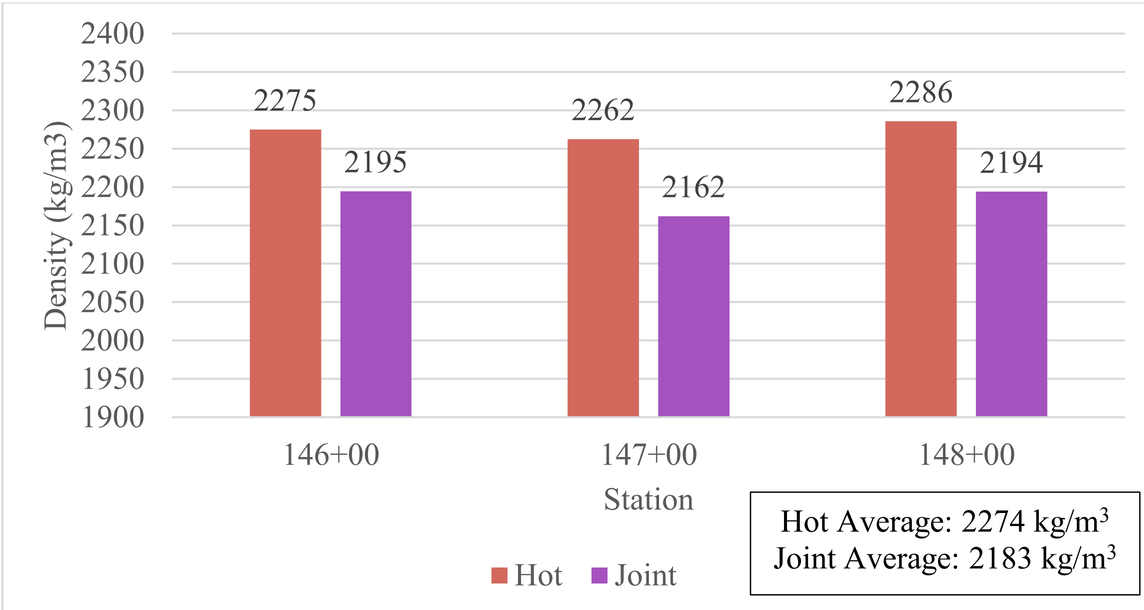

Figure 5.65: SC 11 project lab density measurement

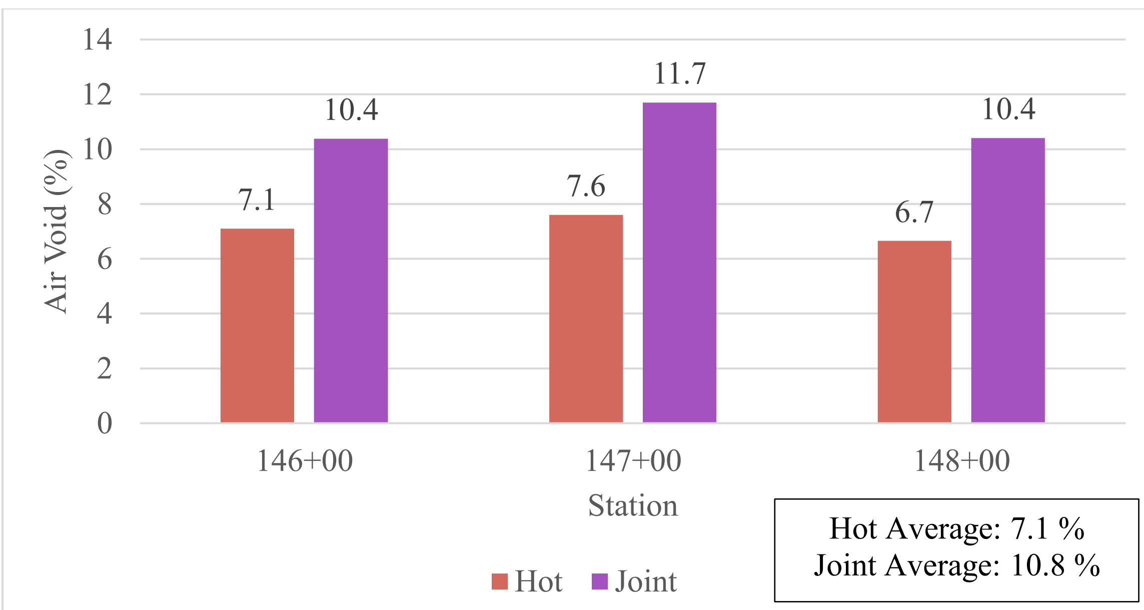

Figure 5.66: SC 11 project air void contents

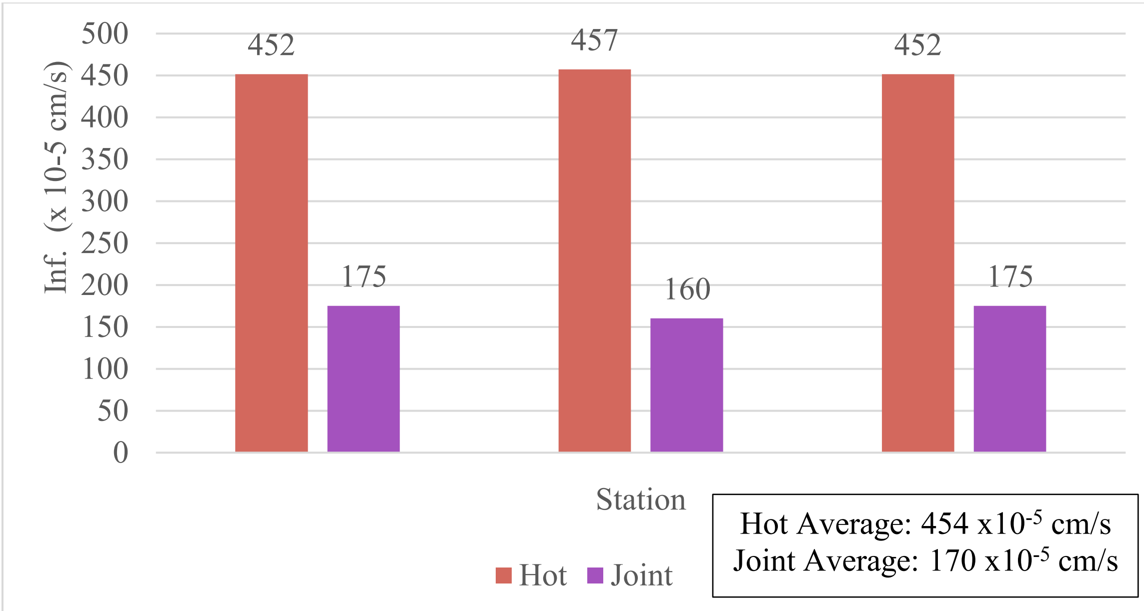

Figure 5.67: SC 11 project in-place infiltration measurement

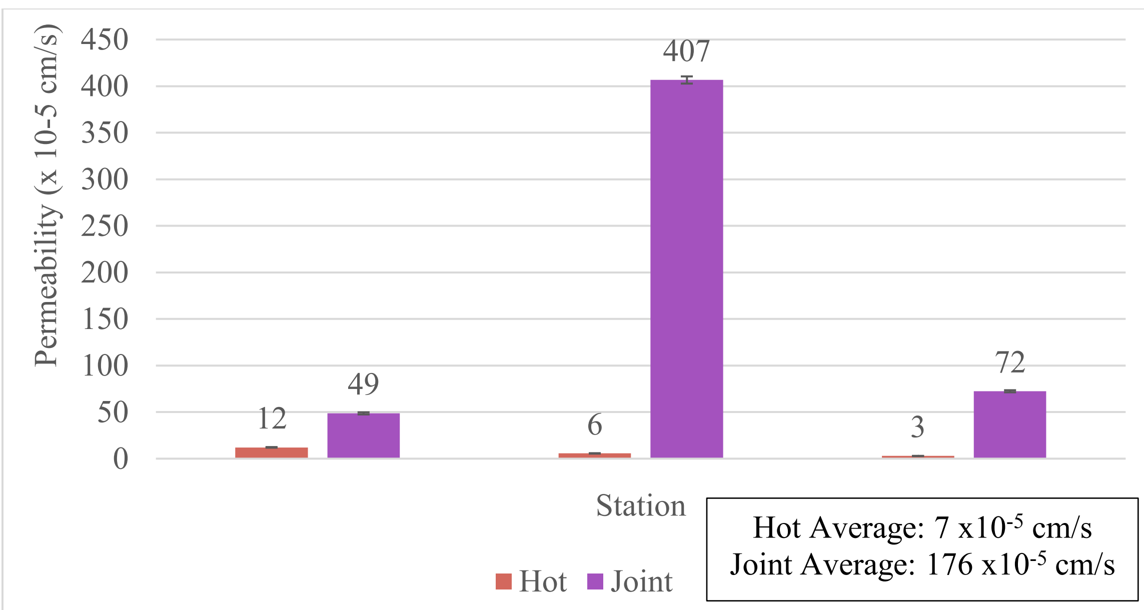

Figure 5.68: SC 11 project lab permeability

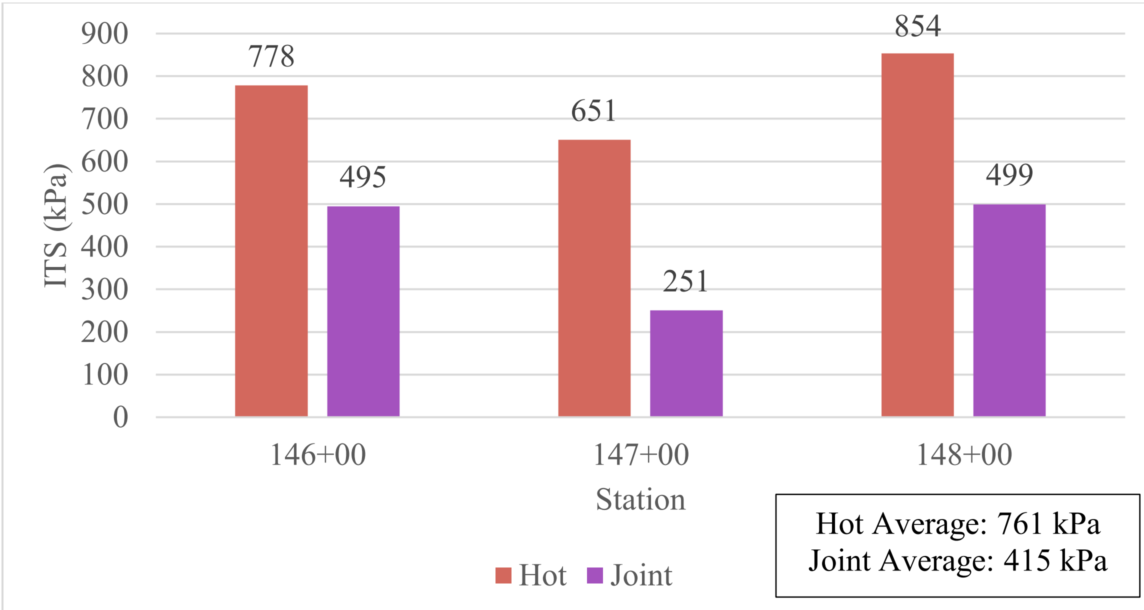

Figure 5.69: SC 11 project dry indirect tensile strength (ITS) measurement

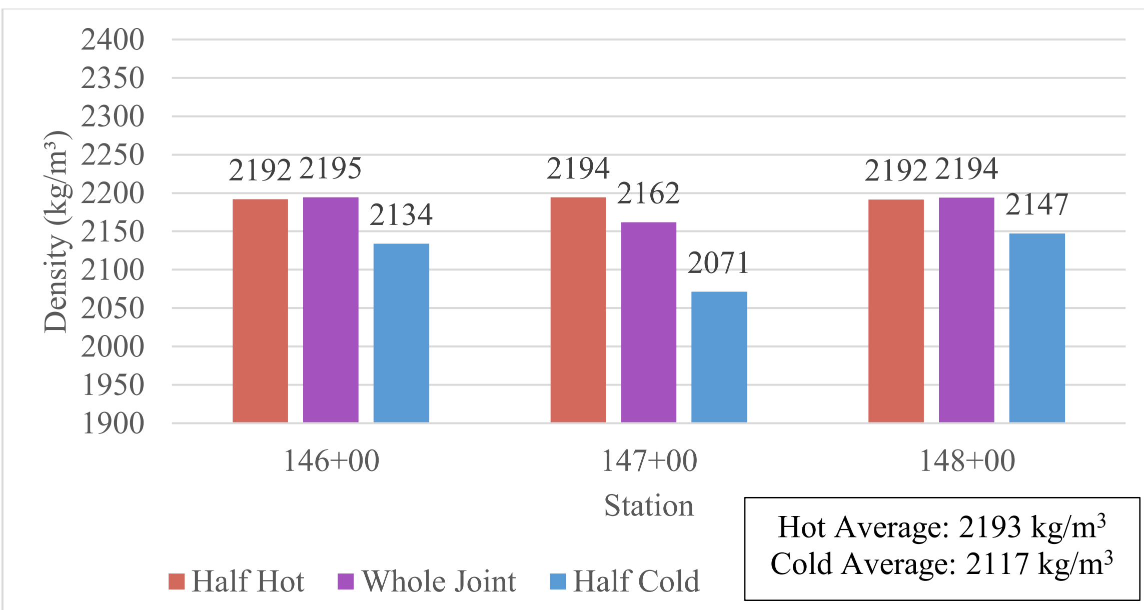

Figure 5.70: SC 11 half cores lab density from the joint cores

Table 5.18 Summary of SC 11 project

(H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	Hot	Joint	Cold	Significant Difference
Field Density (kg/m³)	2274	2293	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	454	170	.	Yes (H vs J)
Lab Density (kg/m³)	2274	2183	.	Yes (H vs J)
Lab Air Void (%)	7.1	10.8	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	7	176	.	No (H vs J)
ITS (kPa)	761	415	.	Yes (H vs J)
Half Lab Density (kg/m³)	2193	.	2117	No (H vs C)

The performance of the hot lane was significantly higher than the joint with respect to field infiltration, lab density, air void, and ITS. It is important to note that all the infiltration results were higher at interior of the mat compared to joint.

The asphalt construction crew for SC 11 project had difficulty in compacting the joint to the same level of the existing lane at the start of the project. This could be because the roller operator was not compacting the joint correctly. To correct the issue, a small vibratory roller was placed in front of the main, vibratory roller to compact the joint as soon as the paver passed by. Because the small roller was only focused on compacting the joint, the quality of the joint may have improved by doing so. The placement of the small roller occurred after the temperature measurement. Therefore, the temperature reading does not reflect the changes in the compaction order.

Other Performance Factors

The performance of longitudinal joints were measured in the field and lab using density, infiltration, permeability, and ITS tests. However, aside from direct measurement, other observations were made regarding the quality of longitudinal joint construction. According to the South Carolina Standard Specifications for Highway Construction (SCDOT 2007), it is required to arrange the width of the lanes to offset the joint of each successive course from the previous course. However, when performing asphalt resurfacing projects, some of the quality control managers stated that it is difficult to determine where the joint of the underlying course is located after milling the surface layer. Offsetting the joint can improve the performance of the joints by minimizing the chance of infiltrated from water seeping through all the joints of different layers. For the future work of asphalt pavement construction, joint locations of underlying courses should be recorded for future resurfacing projects.

During asphalt pavement construction and resurfacing projects, it is sometimes difficult to identify which rolling pattern is practiced due to the limited space at the joint from the incoming traffic. Therefore, the roller operators were not capable of maintaining the hot overlap method without running over traffic cones near the joint. Rather than compacting 6 to 12 in away from the joint or over the joint, it was observed that the majority of the roller drum was over the joint by 3 in or less. In addition, sometimes, the rollers were compacting in a curvy pattern along the joint to avoid traffic cones. It may be helpful to have a camera or mirror attached to the side of the roller for experienced and novice roller operators to see where the wheels are actually passing. Moreover, there should at least 6 to 8 in of space between the joint and the traffic cones, if possible.

Result Summary

Temperature

The temperature of asphalt mix is considered a key component to producing quality asphalt pavement. To observe how the temperature influenced the quality of the joints in this study, the temperature of the mix after a paver passed and the temperature before the first roller pass was measured. The change in asphalt temperatures before compaction from all of projects is illustrated in Figure 5.71 and this bar chart demonstrates that SC 8 had the highest temperature drop after the paver passed by. The SC 8 project was the only project without a material transfer vehicle (MTV) on site, but as mentioned before, the temperature was measured after the first roller pass due to safety reasons. Typically, a MTV helps to reblend the mix from delivery truck and transfers the mix to the paver though a conveyor belt. For many asphalt construction projects, the MTV can improve the quality of pavement by minimizing the thermal and material segregation. Relating to the temperature loss, most projects could also be easily improved by decreasing the distance between the paver and the first roller.

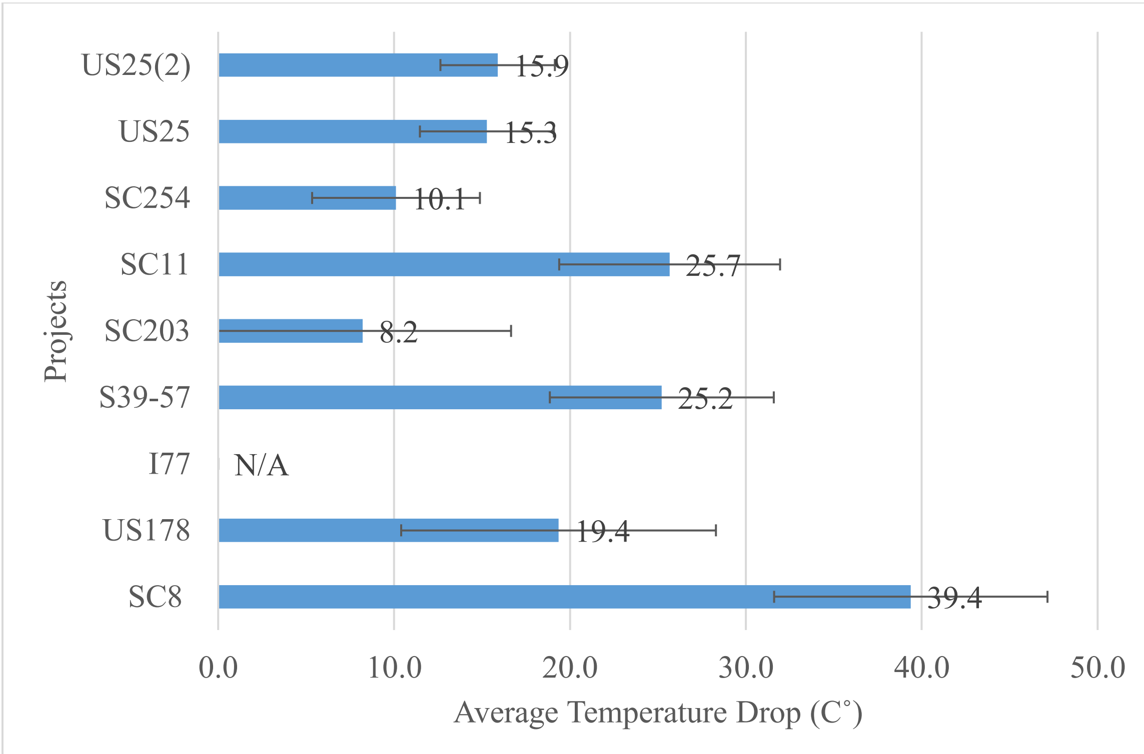

Figure 5.71 Projects temperature drop before the joint compaction

Air Void

The quality of a joint can be assessed by comparing to the quality of interior portions of the pavement. The air void results for all projects' summarized in Table 5.19 and Figure 5.72. In comparison, the air voids of all joint cores had almost twice as much air voids as the hot lane cores. Additionally, all the average air void J/H ratios had higher than 1, indicating higher air void at the joint. This shows that if the surface of the joint is not sealed appropriately, joints are likely to deteriorate from the intrusion of water and air through possible interconnected air pockets. As previously mentioned, air voids could be high at the joint because joints are not compacted appropriately. Even though reducing the air void content at joint to the same level as the hot lane may not be possible because of the hardened edge of cold lane, more effort could be taken to lower the air void content at the joint.

Table 5.19: Air void summary of projects

(SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	Average Void Content				
	Hot (%)	Joint (%)	J/H	J/H SD	J/H CV (%)
SC8	7.6	14.5	1.93	0.277	16.7
US178	6.1	17.0	2.79	N/A	N/A
I77	8.7	10.3	1.18	N/A	N/A
S39-57	7.7	17.8	2.32	0.301	11.7
SC203	8.5	13.5	1.60	0.140	9.7
SC11	7.1	10.8	1.52	0.054	3.7
SC254	7.5	10.8	1.53	0.589	43.9
US25	6.2	12.1	1.95	0.252	12.9
US25(2)	6.2	11.0	1.80	0.223	13.4

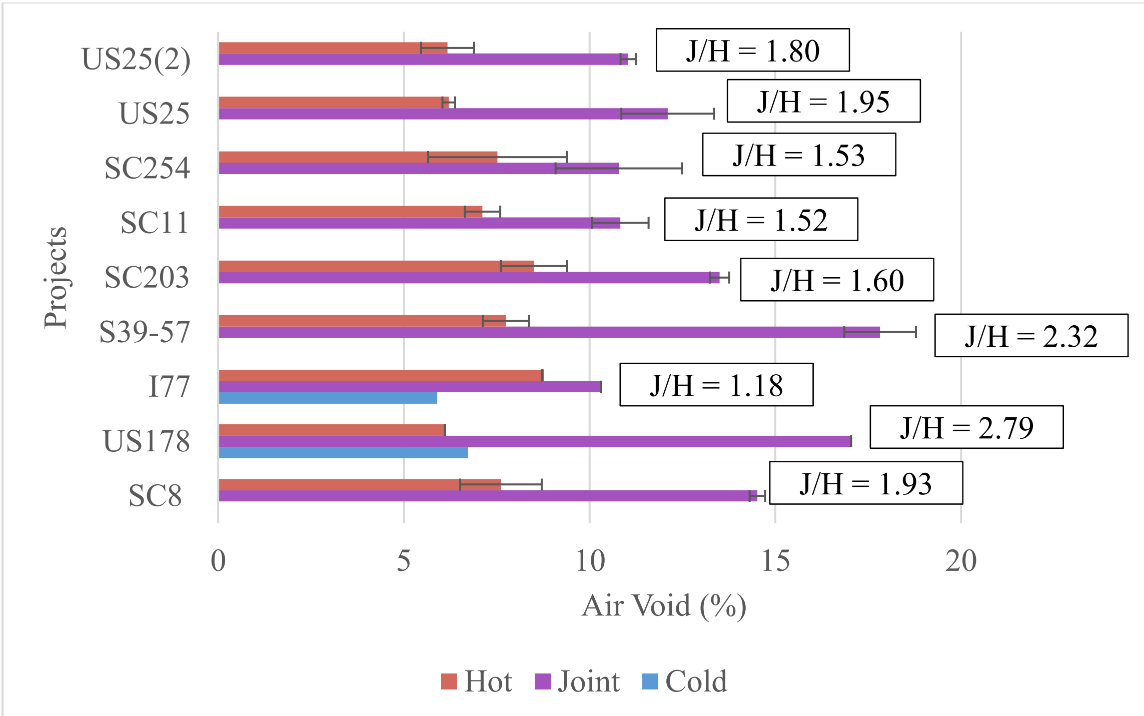

Figure 5.72: Projects air void content (J/H = ratio of joint and hot lane)

Density

The density is the most common method used to monitor the quality of the pavement mat during construction and it also has been one used to check the quality of the joint. From the lab density results summarized in Table 5.20 and Figure 5.73, the performance of joint is significantly lower than the interior of the lane. However, the summarized field density results displayed in Table 5.21 and Figure 5.74 do not show significant differences between the density of the joint and the hot lane. When a comparing the density and lab density, the density gauges accurately determined the density of interior portions of the pavement, assuming lab density results represent the actual pavement quality. However, the density gauges were not able to accurately determine the density of the joints. The majority of field density measurements were off by more than 100 kg/m^3 (6.25 pcf) compared to lab density measurements. Moreover, the average J/H ratios of the field density were closer to 1 compared to the lab density, indicating that there are no differences in performance of the joint and the hot lane. It may be possible that there is a limit to the impedance spectroscopy technology and radioactive responses for checking the quality of the joint due to the high percentage of air voids.

Table 5.20: Lab density summary of projects

(SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	Average Lab Density (kg/m³)				
	Hot (kg/m³)	Joint (kg/m³)	J/H	J/H SD	J/H CV (%)
SC8	2307	2135	0.93	0.011	1.22
US178	2362	2087	0.88	N/A	N/A
I77	2219	2181	0.98	N/A	N/A
S39-57	2262	2015	0.89	0.016	1.85
SC203	2209	2089	0.95	0.007	0.73
SC11	2274	2183	0.96	0.005	0.47
SC254	2246	2167	0.97	0.031	3.25
US25	2283	2139	0.94	0.015	1.58
US25(2)	2282	2164	0.95	0.007	0.78

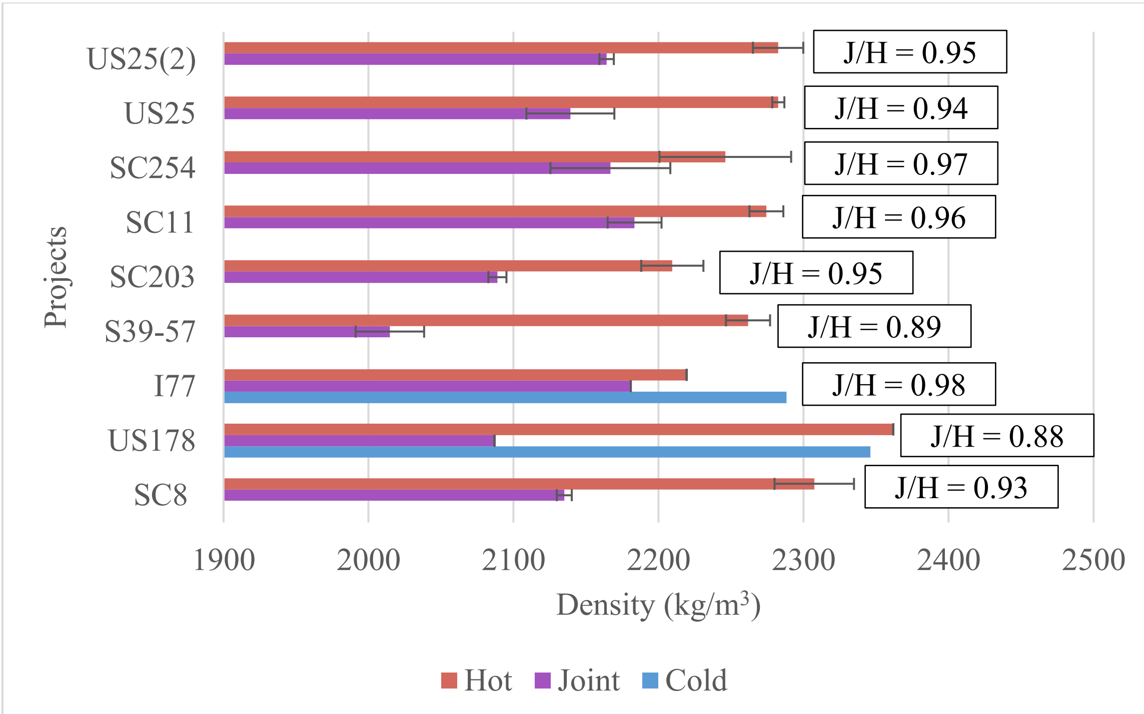

Figure 5.73: Projects lab density from SC-T-68 (J/H = ratio of joint and hot lane)

Table 5.21: Field density summary of projects

(SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	Average Field Density				
	Hot (kg/m^3)	Joint (kg/m^3)	J/H	J/H SD	J/H CV (%)
SC8	2333	2319	0.99	0.007	0.67
US178	2363	2285	0.97	N/A	N/A
I77	2242	2271	1.01	0.009	0.93
S39-57	2274	2258	0.99	0.004	0.38
SC203	2226	2224	1.00	0.009	0.86
SC11	2274	2293	1.01	0.008	0.82
SC254	2275	2249	0.99	0.012	1.19
US25	2250	2191	0.97	0.013	1.31
US25(2)	2269	2266	1.00	0.009	0.86

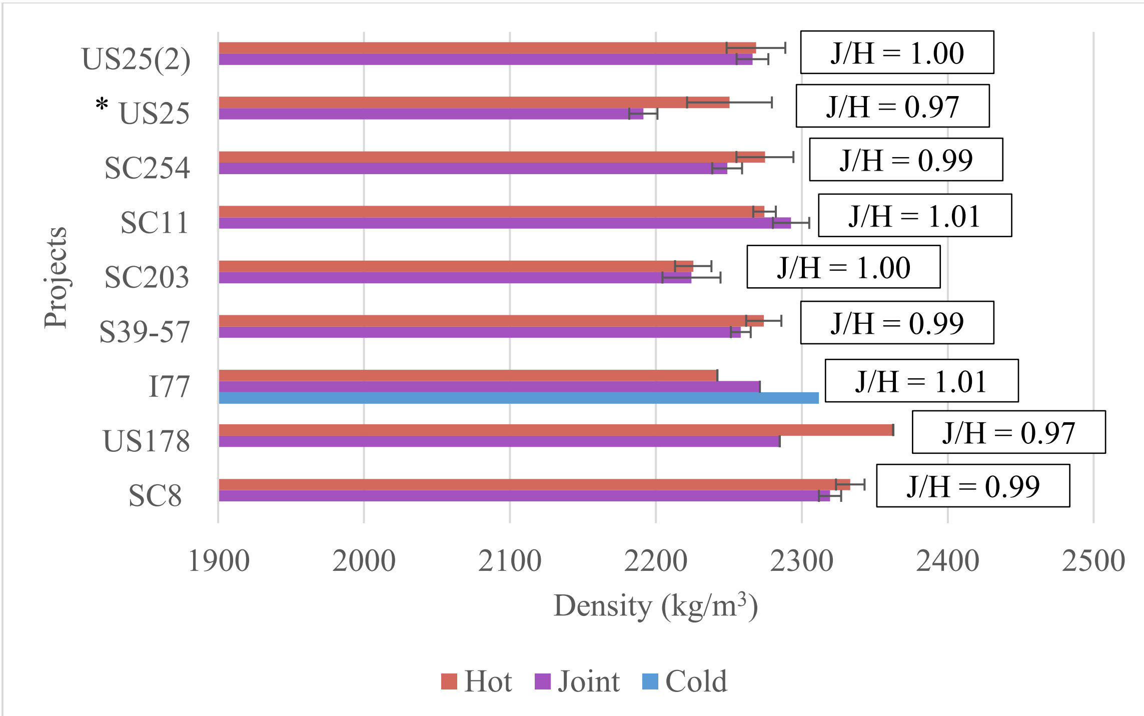

Figure 5.74: Projects field density using a non-nuclear and nuclear density gauge

(J/H = ratio of joint and hot lane, nuclear density gauge marked with *)

All of the in-place density and lab density data are plotted in Figure 5.75 and based on the figure, the relationship between in-place density readings obtained using density gauges and density measurement from SC-T-68 have a weak linear relationship. Similarly, Chen et al. stated that the PaveTracker, another non-nuclear density gauge, does not have a strong relationship to AASHTO T 166 (SC-T-68) nor the CoreLok method, which is another method used to measure core density in the lab (2013). As previously mentioned, the relationship improves if only the in-place density and lab density of the hot cores are compared without joint data as shown in Figure 5.76. To observe if there was a pattern among just joint data, Figure 5.77 was created, but no pattern was observed.

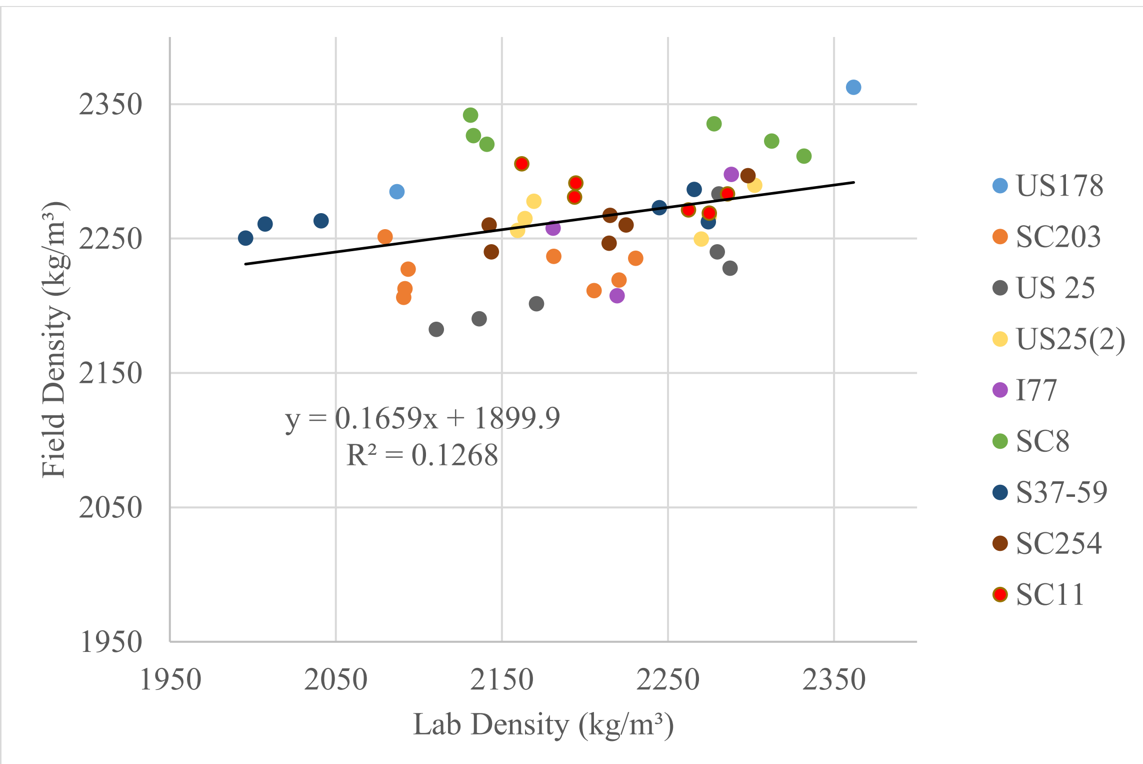

Figure 5.75 Relationship between field density and lab density of all data

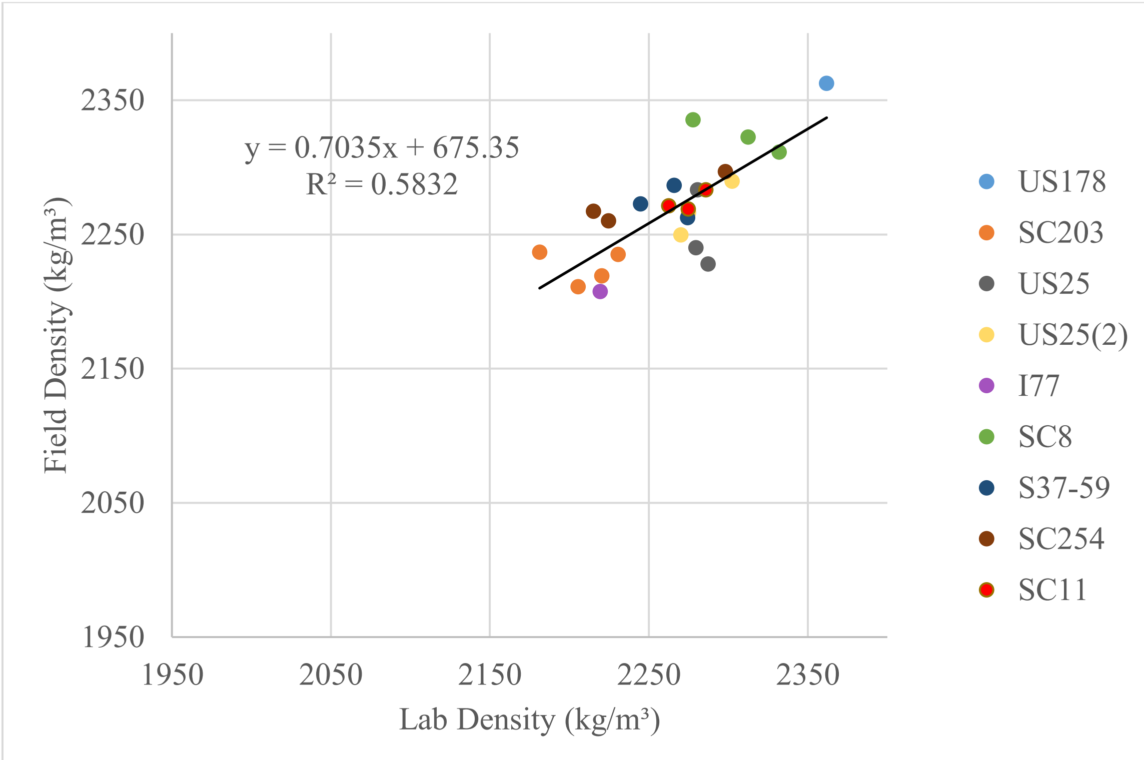

Figure 5.76: Relationship between field density and lab density of only hot core data

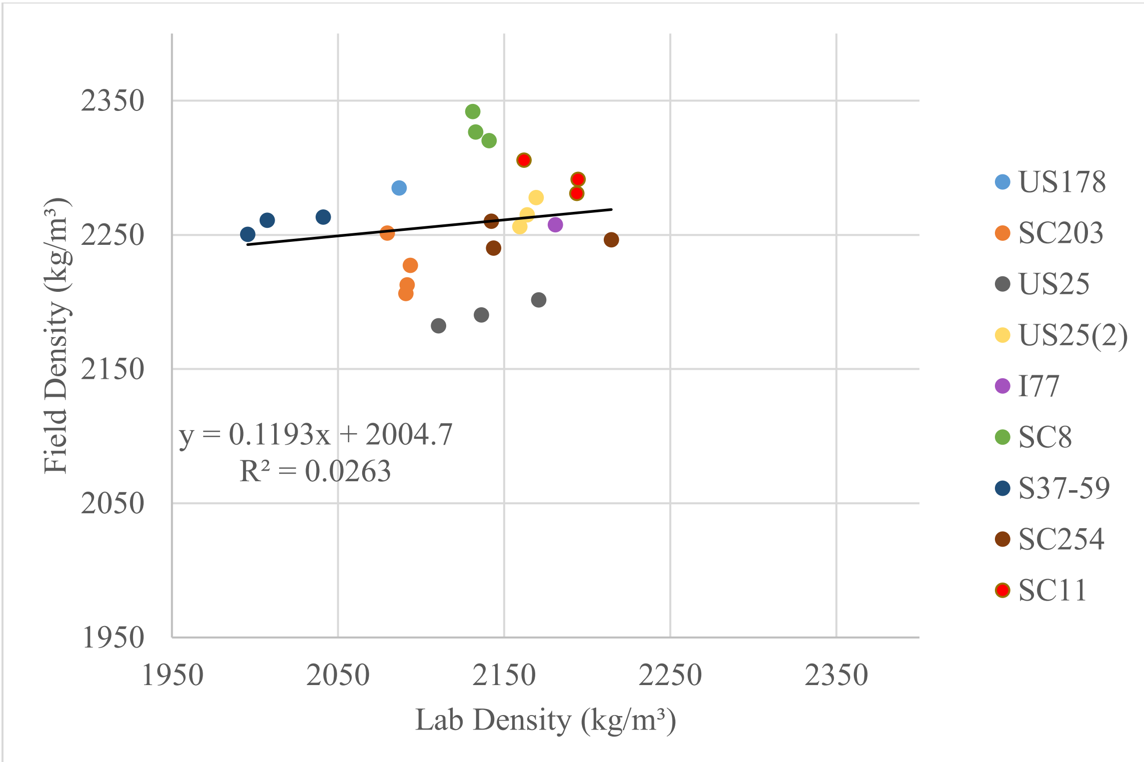

Figure 5.77: Relationship between field density and lab density of only joint core data

Permeability

Longitudinal joint cracking occurs due to weak density and inadequate materials at the joint, but it is believed that most deteriorations occurs when water starts to penetrate at the joint. Mallick et al. stated two reasons that field infiltration measurement is needed when evaluating the performance of asphalt pavement at the longitudinal joint. First, the permeability is more related to durability issues resulting from moisture damage, premature oxidation and cracking. Second, they also referenced other authors' experiences describing the difficulty of determining density at the joint using a field density gauge (2006).

When all of the in-place infiltration results (Table 5.22 and Figure 5.78) of the hot lane and the joint are compared, the infiltration at the joint was slightly higher than the hot lane. In some cases, the infiltration rate at the hot lane was higher than the joint. The laboratory permeability results (Table 5.23, and Figure 5.79) of the hot lane and the joint followed the same trend of in-place infiltration results, but there were drastic differences between the hot lane and the joint. The reason for the higher permeability measurements at the joint compared to the hot lane is high air void and low density at the joint. Zube concluded that dense-graded asphalt with greater than 8% air void content will experience high permeability (1962), and Choubane et al. recommend the air void to be 6% or less to achieve impermeability (1998). In contrast to these two previous studies, Brown et al. claimed compacted asphalt with 5% to 7% air void content could still measure high permeability coefficient (2004).

When the field infiltration and lab permeability results are compared, the results are significantly different from one to another for the hot lane and the joint. The significant differences can be seen in J/H ratios also. The differences could be because, in the field, the water can move horizontally after penetrating the surface of the asphalt for the infiltration test, but the water is only allowed to move vertically for lab controlled permeability test. Even though the area of interest was not the same for the joint in-place infiltration and lab permeability, measuring the in-place infiltration 1 ft from the actual joint should still well represent the quality of the joint. If the in-place infiltration was conducted on the actual joint without the water leaking issue, then the value could be higher than the purple bars that are depicted in Figure 5.78. The standard deviation of the two figures show that the lab permeability results are more repeatable. Similarly, Chen et al. stated that the NCAT permeameter is less reliable than the in-lab K-W permeameter (FM-5-565) and concluded no permeability criteria was determined due to its' poor relationship with in-place air voids (2013).

Table 5.22: Field infiltration summary of projects

(SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	Average Field Infiltration				
	Hot (x 10^{-5} cm/s)	Joint (x 10^{-5} cm/s)	J/H	J/H SD	J/H CV (%)
SC8	281	803	5.62	6.61	118
US178	.	.	N/A	N/A	N/A
I77	.	.	N/A	N/A	N/A
S39-57	656	918	1.60	0.82	51
SC203	661	843	1.75	1.00	57
SC11	454	170	0.38	0.02	6
SC254	745	893	4.01	5.40	135
US25	229	783	3.66	1.45	39
US25(2)	273	428	2.41	2.65	110

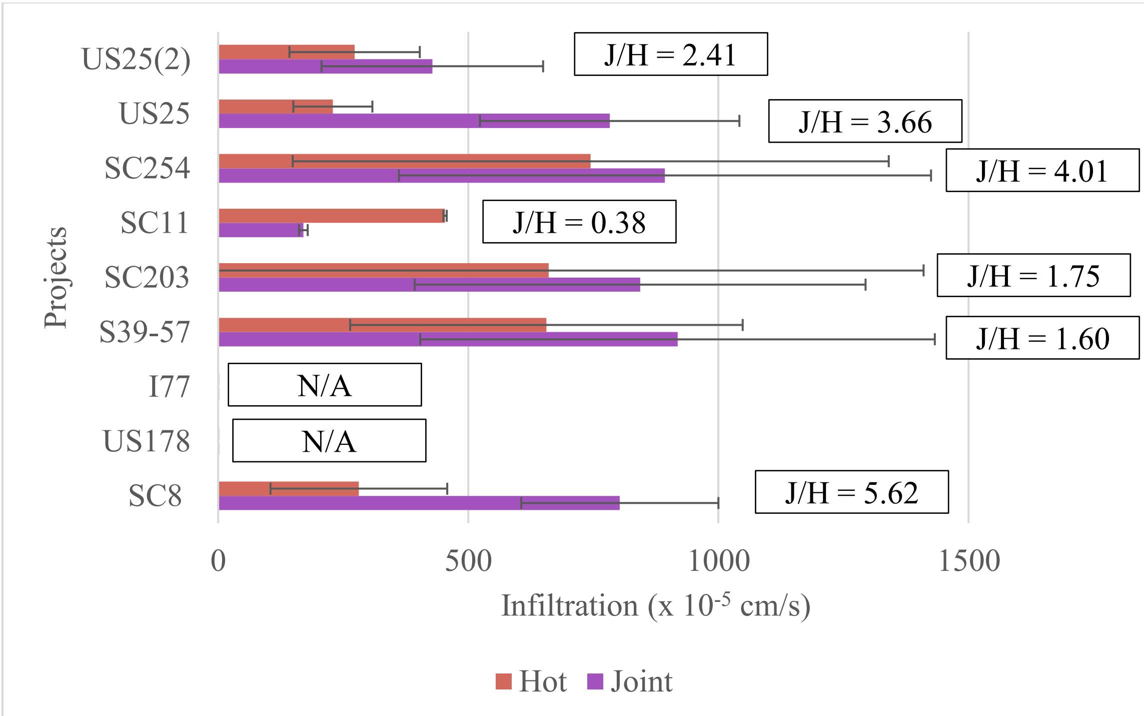

Figure 5.78: Projects in-place infiltration (J/H = ratio of joint and hot lane)

Table 5.23: Lab permeability summary of projects

(SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	Average Lab Infiltration				
	Hot (x 10^{-5} cm/s)	Joint (x 10^{-5} cm/s)	J/H	J/H SD	J/H CV (%)
SC8	3	241	137	74	54
US178	0	1176	64066	N/A	N/A
I77	752	3586	1	N/A	N/A
S39-57	22	1540	159	175	110
SC203	21	716	67	45	67
SC11	7	176	34	35	103
SC254	34	129	21	33	157
US25	13	148	45	49	111
US25(2)	8	219	97	133	138

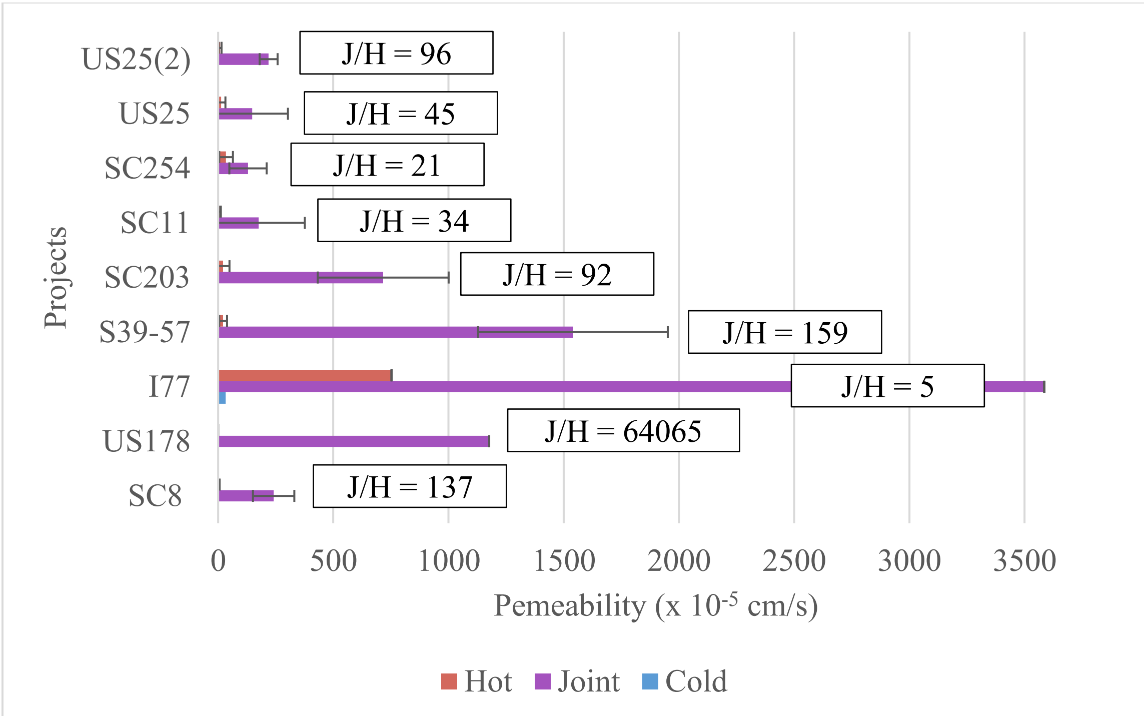

Figure 5.79: Projects lab permeability following FM 5-565

The non-linear, direct relationship between lab permeability and density is displayed in Figure 5.80. This shows that when the density of the asphalt decreases, the permeability increases exponentially. When the asphalt pavement is less dense, it results in higher void content allowing for the water flow thorough the asphalt material structure.

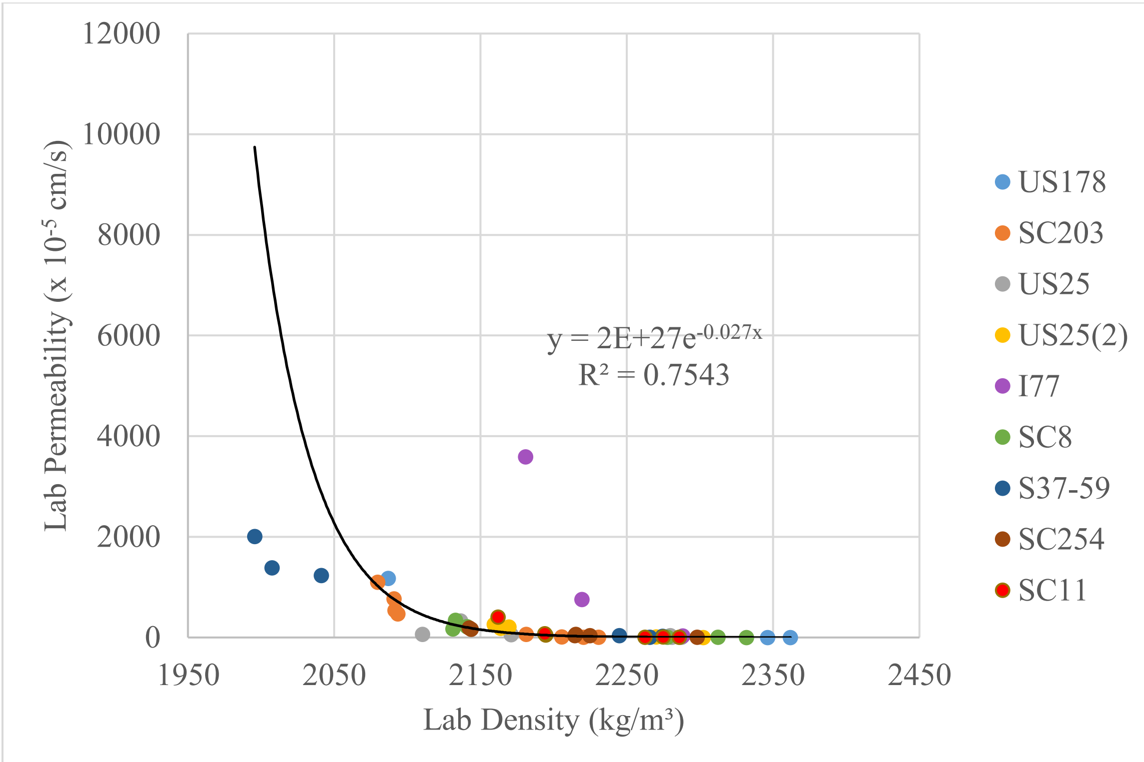

Figure 5.80 Relationship between lab density and lab permeability

Indirect Tensile Strength

The indirect tensile strength testing is typically used to measure moisture susceptibility of asphalt specimen by applying indirect tension, but it can also be used to determine the bonding strength of the joint. If the indirect tensile is high, then it indicates that the bond strength at the joint is high also. The ITS results (Table 5.24 and Figure 5.81) follow the same trend as density (and air void). The ITS J/H ratios were much lower than the density J/H ratios. The ITS of joint cores were much lower than the ITS of the hot lane cores because the joint cores are composed of the cold lane bonded to the hot lane while the hot lane cores were only composed of single material. Temperature differences between the cold and the hot lane cause a weak bond between the two edges. Additionally, the joint is usually not well compacted compared to the remainder section, which results in weaker ITS at the joint. To minimize issues at the joint, quality control managers and inspectors need to ensure there is a proper compaction and may need to use stronger tack coat to minimize longitudinal joint cracking.

Table 5.24: Indirect tensile strength summary of projects

(SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	Average ITS				
	Hot (kPa)	Joint (kPa)	J/H	J/H SD	J/H CV (%)
SC8	672	348	0.52	0.183	35.5
US178	1019	254	0.25	N/A	N/A
I77	837	285	0.34	N/A	N/A
S39-57	625	120	0.20	0.112	54.5
SC203	484	239	0.56	N/A	N/A
SC11	761	415	0.54	0.132	24.7
SC254	744	495	0.67	0.091	13.6
US25	753	392	0.52	0.064	12.5
US25(2)	657	367	0.56	0.045	8.0

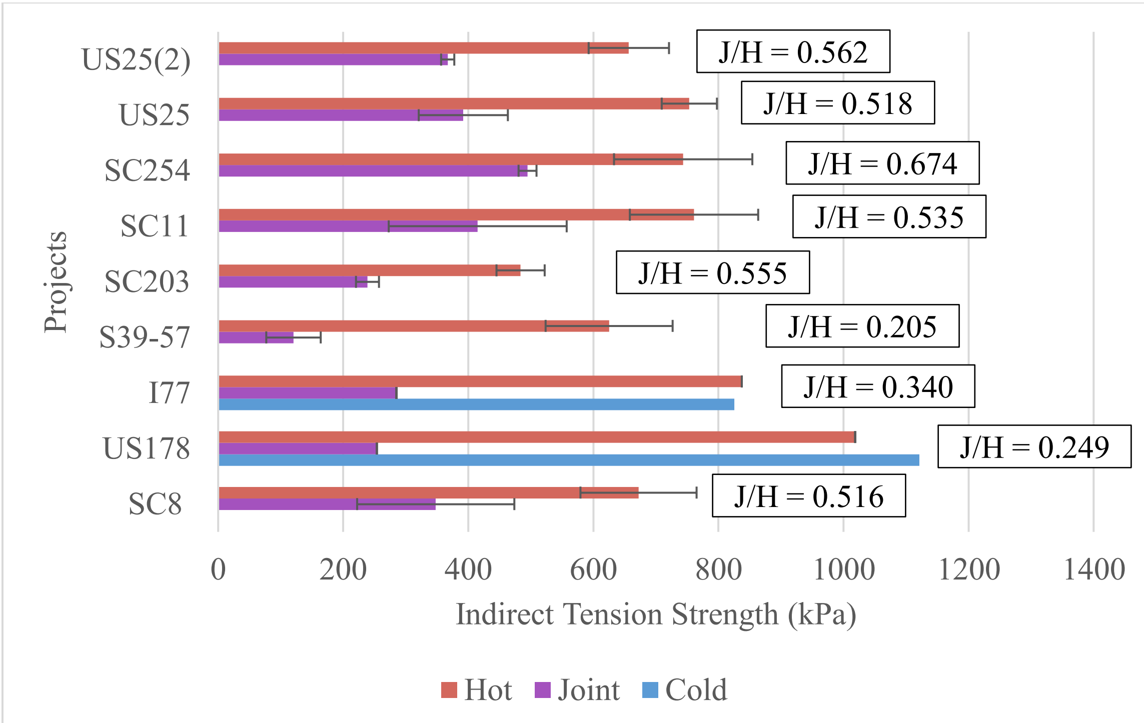

Figure 5.81: Projects indirect tension strength (J/H = ratio of joint and hot lane)

The linear relationship between lab density and ITS results are shown in Figure 5.82, which resembles findings by Chen et al. (2013). The hot and cold lane and joint data are combined into one figure and the result still showed a direct, strong relationship between two variables.

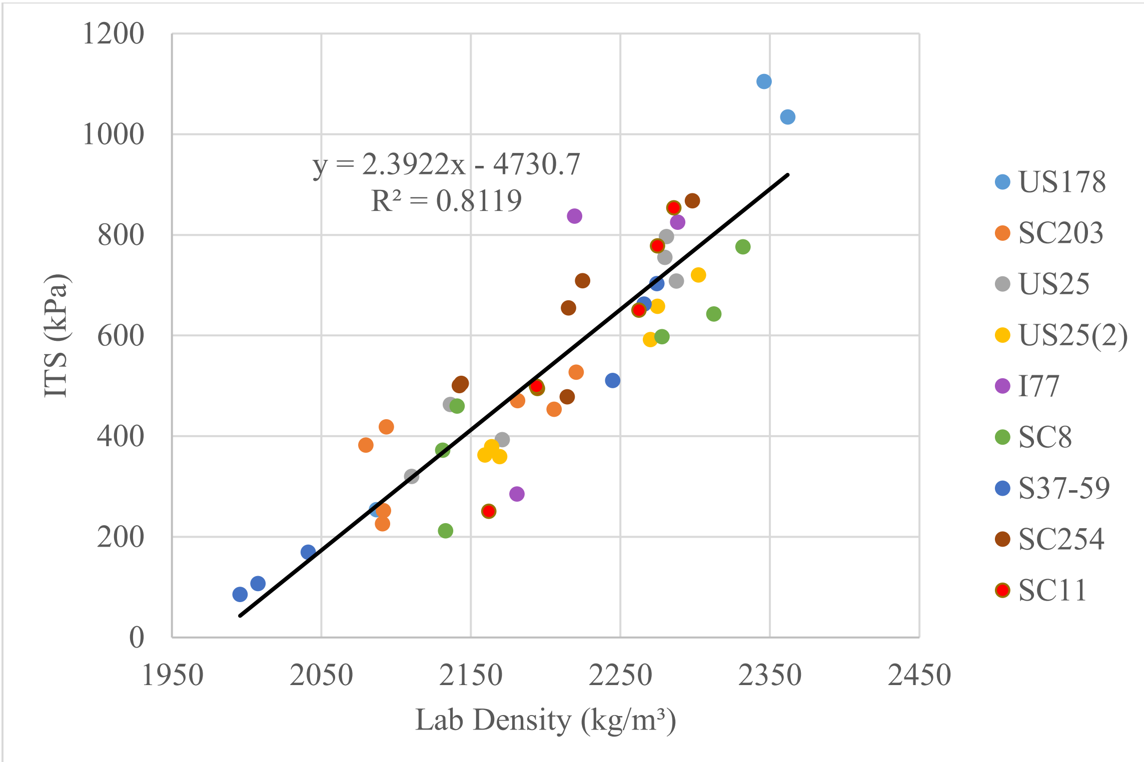

Figure 5.82: Relationship between indirect tensile strength and lab core density

Half Core Density

The broken joint cores after the ITS testing were tested using the SC-T-68 method to determine the density of the hot lane and the cold lane at the joint. All of the densities of half cores (the hot and cold lane) are shown in Table 5.25 and Figure 5.83. Except for the SC 254 and SC 8 projects, all the hot half cores had slightly higher density results than the cold half core, confirming the results from Estakhri et al. (2011). The hot half cores have a tendency to measure higher density because the hot lane is constructed on confined edges and the cold lanes are constructed on unconfined edges. The confined edges provide structural support for asphalt mix to lean against during construction while cold lane edges are sloughing.

Table 5.25: Half core density summary of projects

(SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	Average Half Core Density				
	Hot (kg/m³)	Joint (kg/m³)	C/H	C/H SD	C/H CV (%)
SC8	2108	2117	1.00	0.035	3.46
US178	2095	2056	0.98	N/A	N/A
I77	2188	2107	0.98	N/A	N/A
S39-57	2011	1973	0.98	0.019	1.95
SC203	2125	1999	0.95	0.014	1.48
SC11	2193	2183	1.00	0.009	0.92
SC254	2127	2166	1.02	0.015	1.44
US25	2141	2106	0.98	0.020	2.07
US25(2)	2148	2106	0.98	0.005	0.54

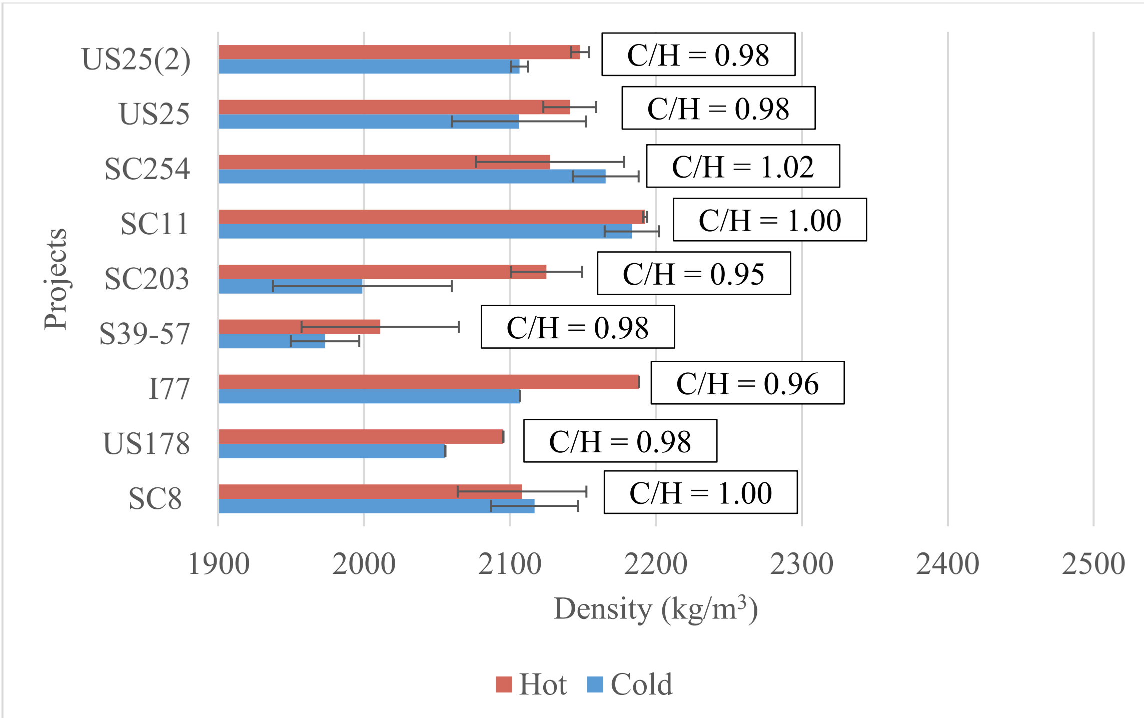

Figure 5.83 Projects half core density (C/H = ratio of hot and cold lane at joint)

Statistical Analysis

The performance of individual site, joint type, mix type, thickness, and nominal maximum aggregate size (NMAS) could not be compared through tables or figures alone. To find how changes in variables influence the performance of the joint compared to the middle of the hot lane, the JMP data analysis software was used to perform analysis of variance (ANOVA) by running each pair, student's t-tests with significance of 5%. The connecting letters report for the site (Table 5.26), joint type (Table 5.27), mix type (Table 5.28), thickness (Table 5.29), and NMAS (Table 5.30) are presented below.

Table 5.26: Project sites ANOVA connecting letters report

(* = Nuclear density gauge reading)

Site	Temperature Drop	Field Density	Field Permeability	Lab Density	Lab Permeability	ITS
SC 8	A	BC	A	D	B	ABC
US 178	BC	D	.	E	A	CD
I 77	.	A	.	A	B	BCD
S 39-57	B	BC	A	E	B	D
SC 203	D	ABC	A	BCD	B	ABC
SC 11	B	AB	A	ABC	B	ABC
SC 254	CD	CD	A	AB	B	A
SC 25	CD	D*	A	CD	B	ABC
SC 25(2)	CD	ABC	A	ABCD	B	AB

Among all of the asphalt surfacing projects, no difference in performance was found in field infiltration and only the US 178 project was significantly different from other projects in lab permeability. Statistically, the US 178 project had the worst performance in lab permeability because the middle of the hot lane was almost impermeable while the joint was highly permeable. The results may be altered if there more were core samples from the US 178 project. For field density and lab density, I 77 outperformed in field density and lab density and for the ITS results, SC 254 outperformed other projects. It is difficult to pinpoint why a certain project's joints performed better than another site as there are many variables in asphalt pavement construction, and more research needs to be conducted with controlled variables.

The connecting letters report of joint construction types of butt joint and safety edge show no significant improvement on the joint for the different performance indicators (Table 5.27). More joint construction techniques need to be evaluated for the future research.

Table 5.27: Joint types ANOVA connecting letters report

Joint Type	Field Density	Field Infiltration	Lab Density	Lab Permeability	ITS
Butt	A	A	A	A	A
Safety Edge	A	A	A	A	A

There were 3 different mix types (surface type A, B, and C) and surface type A showed increased field density of the joint compared to the surface type C (Table 5.28). Surface types A and B showed significantly greater joint performance as indicated by lab density results compared to the surface type C. The surface A mix type may perform better than type C because type A contains PG 76-22 binder which requires higher production temperature and allows pavement to be compacted at a higher temperature. In addition, the surface type A and B mix require more compaction to account for the higher volumes of traffic of the road than type C. Typically, the more compaction is done, the more consolidation of material is observed until the peak point is reached.

Table 5.28: Mix types ANOVA connecting letters report

Mix Type	Field Density	Field Infiltration	Lab Density	Lab Permeability	ITS
Surface A	A	.	A	A	A
Surface B	AB	A	A	A	A
Surface C	B	A	B	A	A

There were 3 different thickness (1.5, 2.0, and 2.5 in) of surface layers and the results of the statistical analysis showed that the 2 in and 2.5 in thick joints were more likely to perform better in lab density and ITS results than 1.5 in thick joint (Table 5.29). The thicker joint will likely increase density because there is more asphalt material to compact and the increase in density results in increase in ITS.

Table 5.29: Thickness ANOVA connecting letters report

Thickness	Field Density	Field Infiltration	Lab Density	Lab Permeability	ITS
1.5 in	A	A	B	A	B
2.0 in	A	A	A	A	A
2.5 in	A	A	A	A	A

The nominal maximum aggregate size (NMAS) is the sieve size that is one size larger than the first sieve that retains more than 10% aggregate. Out of the 9 resurfacing projects included in this study, there were only 2 NMAS categories (9.5 mm and 12.5 mm). The ANOVA revealed there was no significant differences between the 2 different NMAS.

Table 5.30: NMAS ANOVA connecting letters report

NMAS	Field Density	Field Infiltration	Lab Density	Lab Permeability	ITS
9.5 mm	A	A	A	A	A
12.5 mm	A	A	A	A	A

CHAPTER SIX

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Premature longitudinal joint cracking typically occurs at the joint where two adjacent pavement lanes meet and failure is typically due to low density, high permeability, and/or low bonding strength. This study observed construction of longitudinal joints in 9 asphalt paving projects in South Carolina and compared the performance of the joint and interior portion of the hot lane. Based on the density, permeability, and indirect tensile strength (ITS) results from this research, conclusions related to the performance of longitudinal joints considering individual site, surface mix type, thickness, and nominal maximum aggregate size (NMAS) were found. In addition, the effectiveness of in-place density, lab and in-place infiltration, and ITS were evaluated based on the results.

Conclusions

Based on the results of this study, the following conclusion were made:

- Out of the 9 asphalt surfacing construction projects evaluated in this study, 8 projects showed significant differences between the interior portion of the pavement and the joint based on density, permeability, and/or ITS results.
- As the density of asphalt increased, the ITS increased linearly and as the density of asphalt decreased, the lab permeability increased exponentially.

- All the field testing results had higher variability than lab testing results, indicating the field testing may not be as reliable for checking the quality of the joint.
- The density gauges were more capable of accurately measuring the density of the interior portion the lane when using the cores as a baseline, but the accuracy decreased when measuring density of the joint.
- The safety edge joint technique without compaction on the wedge did not significantly improve the performance of the joint compared to the butt joint technique.
- Using the surface type A or B mix instead of type C and increasing the depth of asphalt pavement, statistically improved quality of the joint.
- The survey indicated that more research needs to be conducted in South Carolina to determine the effectiveness of other joint construction techniques.

Recommended Best Practices for Longitudinal Joint Construction

- Asphalt pavement layer should be at least 4 times the nominal maximum aggregate size (NMAS) for coarse aggregate mix and 3 times the NMAS of fine aggregate mix.
- Use finer gradations and the smallest NMAS mix to make the surface less permeable and add more binder to the mix to lower the air voids.
- Develop a communication and training program to re-educate roller operators and field quality control managers.

- Asphalt deliveries for truck drivers should be paid per number of loads delivered instead of per hour to minimize the cooling of asphalt.
- Extend augers and tunnels from 12 to 18 inches to the end of the gate to guarantee asphalt mix is carried to the joint to minimize segregation or temperature loss.
- Use material transfer vehicles to minimize temperature loss and segregation.
- Maintain straight joint lines during asphalt pavement construction.
- Clean the matching edge with a broom or a motorized road sweeper to remove loose material before the paver passes and check that the edges are leveled.
- When applying tack coat to the joint, extend few inches over the joint to ensure edge are fully tacked. Then, make sure a proper amount of time has passed for curing.
- Consider using joint adhesive or higher stronger tack coat to improve the performance of joint.
- Maintain a uniform head of material at the auger to ensure enough material is present at the joint throughout the paving operation.
- "Ensure the height of the loose lift is higher than the adjacent lift so the final compacted height will be slightly higher than the previously constructed mat" (Survey Respondent #38).
- Pavers should include tamping or vibrating features near the edge of the paver to provide higher densities at the unconfined edge.

- Make sure there is enough for the space roller operator to compact over the joint if possible or increase the roller operator's visibility at the edge of the wheel using a live view camera or mirror.
- Compact the joint using the hot pinch and overlap method for the first pass and the second pass, respectively. However, if there are signs of cracking along the pinch lines, then use the overlap method instead. If hot overlap method is used as the first pass, the overlap at the joint should be 0.1 inch higher to ensure no bridging effect is occurring from the roller.
- Use a pneumatic tire roller to knead the uncompacted asphalt due to bridging effects and use a finish roller to remove tire markings.
- Make sure all rollers (breakdown, intermediate, finish) are compacting at the joint.
- For the sloped edge or safety edge, compact the face of the wedge using a steel side roller or a tag-along roller and make sure there is a notch on the top of the wedge.
- Do not lute or rake the overlapped material unless necessary. If the overlap exceeds 1.5 inches, then carefully remove the excessive material using a flat headed shovel. If luting is absolute necessary, then only bump to the joint.
- Use a nuclear or non-nuclear density gauge to monitor the quality of the joint, but do not solely depend on the instrument. If possible, cutting cores from the joint to measure density is the best way of checking the quality at the joint.

Recommendation for Future Research

For future longitudinal joint construction research, a lengthy highway test section is needed to reduce the variability of measurements with one contractor for the project. Working with multiple construction companies increases variability on compaction of roller operators, luting practice, amount of material overlapped over the joint, timing of truck deliveries, and many more. Furthermore, different types of joint construction techniques need to be researched and constructed on South Carolina roads to determine what are the best and most suitable joint construction techniques considering the traffic, cost, repeatability, and timing. Based on the survey responses, the performance of joint adhesives, notched wedge joint, and sequential mill and fill joint construction techniques should be examined. For the compaction of the joint, hot pinch method need to be researched compared to the hot overlap method.

APPENDICES

Appendix A

Survey Monkey Questions

Q1) What is your contact information?

Q2) What agency or company do you work for?

Q3) What is your current position?

Q4) About how many years have you been involved with asphalt pavement construction?

Q5) What rolling methods that your crews commonly practice in the field for a first pass?

Q6) What rolling methods that your crews commonly practice in the field for a second pass?

Q7) What rolling methods that your crews commonly practice in the field for a third pass?

Q8) In your opinion, what is the best rolling method for longitudinal joints through visual, density, or permeability observation?

Q9) Are there any obstacles to using the joint compaction method that you consider to be the best? Please explain.

1. Respondent did not complete this question.
2. Maintaining traffic because pinching the joint requires the roller to be mainly in the adjacent lane when we have a lane closure for a 2 lane roadway
3. Traffic
4. Respondent did not complete this question.
5. Contractor buy in.
6. Joint needs to be straight and paver needs consistent feed of material and overlap of material and roller needs to be consistent
7. Timing and distance away from screed.
8. Keeping straight lines on the first pass so there is the same amount of uncompacted material along the joint. Don't want one inch in some areas and six inches in other areas.
9. No
10. Respondent did not complete this question.
11. Respondent did not complete this question.
12. Trying to get the crew to remember to do it all the time

13. Traffic. When on a narrow road it becomes dangerous for our employees to get too far over in the other lane to perform a cold roll. For night work, it is too hard for the operator to see to perform a hot pinch.
14. Respondent did not complete this question.
15. The hot overlap method requires a skilled lute man to ensure there's enough excess asphalt material to be able to pack the longitudinal joint during compaction. This requires a man walking the longitudinal joint and occasionally being in the adjacent travel lane, which is a problem on busy roads. I have not seen the Hot Pinch method used enough and consistently to have a high confidence level with, but it may work as well or better than Hot Overlap.
16. None other than lane closure.
17. Respondent did not complete this question.
18. Depends on mix type, the pinch seems to work better on coarser mixes (S-A, ST-B, and Intermediate and Bases).
19. Respondent did not complete this question.
20. Getting the roller operators to correctly administer the application.
21. Respondent did not complete this question.
22. Respondent did not complete this question.
23. The obstacles are getting the roller operators to do it as they should.
24. Respondent did not complete this question.
25. Respondent did not complete this question.
26. Not to my knowledge unless it is not a clean, level and straight edge line to pinch.
27. Most old roads in historic areas do not permit vibrations therefore, hot overlap is what is used most in resurfacing in our area
28. Respondent did not complete this question.
29. Respondent did not complete this question.
30. Respondent did not complete this question.
31. Respondent did not complete this question.
32. Respondent did not complete this question.
33. Respondent did not complete this question.
34. Maintaining a safe work zone by separating the traveling public and the asphalt roller.
35. There is difficulty in overlapping joints during narrow roadway construction. Hot pinch may be the best application in these circumstances
36. Respondent did not complete this question.
37. No
38. you have to roll the joint when is hot.
39. Respondent did not complete this question.
40. This may cause the first pass beside the cold lane to get overlooked.

Q)10 How do you maintain straight joint lines during asphalt pavement construction?

Q)11 What do you do with excess overlap material prior to compaction?

Q)12 ased on your experience, please rate the preference of the following joint construction practices for matching existing asphalt pavements.

Q13) Please explain why some of construction practices are most preferred.

1. Per the Specifications
2. Respondent did not complete this question.
3. Respondent did not complete this question.
4. I think you get the best with the wedge.
5. Respondent did not complete this question.
6. I think it is preferred because it is what we are familiar with. Not as familiar with other methods, but I think one of the other methods could create a better joint, one that does not crack as easily and offers better density.
7. Tradition and ease of use, no extra equipment or methods, not much proof these days that different methods are better.
8. Too many parts makes things over-complicated and paving crew employees aren't necessarily known for their mechanical aptitude or troubleshooting capabilities.
9. Most practical and effective
10. These are the practices most observed in the field.
11. Ideally, we are looking for a uniform distribution of HMA across a mat. Some of the practices suggested encourage a variation of ones across a mat.
12. Butt joint is most preferred because of cost and ease of construction. Joint adhesive along with cutting wheel in my opinion is the best to get a solid joint but is very expensive to do.
13. Respondent did not complete this question.
14. Respondent did not complete this question.
15. I have not used or seen most of these methods except the butt joint method, so I can't comment on preference.
16. Proved the best joint performance
17. Respondent did not complete this question.
18. We typically cant do echelon paving unless we have new construction due to traffic control. I think the safety wedge mounted inside paver (Satterfield) on both side is a good tool. No additional side roller used to compact. The joint adhesive could be done with conventional tack or PG.
19. Echelon paving allows a better bond between the 2 mats since they are both placed within hours of each other. This is rarely done since most multiple lane highways are under heavy traffic and dual paving isn't feasible.
20. The Echelon Paving method provides an almost seamless joint.
21. Respondent did not complete this question.
22. Respondent did not complete this question.
23. In my experience the ones I chose are the ones I have seen in the passed and works the best.
24. I've seen best results with a Butt Joint.

25. Respondent did not complete this question.
26. Butt joint with adhesive has always been the way I have seem it done mostly but i also like the Echelon Paving but it makes keeping a rate and oversight a bit difficult**.**
27. most resurfacing contracts have either mill and fill or butt joints
28. Have only seen butt joints
29. Must confine and compact the sloped material during lifts as well as final lift.
30. Respondent did not complete this question.
31. Respondent did not complete this question.
32. Most commonly used
33. Respondent did not complete this question.
34. They allow for a better bond between two lanes. Interlocking allows for a tight bond. Having hot asphalt being pulled beside hot asphalt is the best practice because the two lanes form together as one eliminating a joint.
35. Practices such as echelon paving, joint adhesive, joint maker, and sequential mill and fill are all positive practices for asphalt paving but are not always utilized nor are always necessary for certain paving circumstances. The most efficient, long-withstanding practice for a successful joint has always been a butt joint.
36. I have more experience using butt joint and sequential mill and fill.
37. Butt Joint is the only practice we use
38. Edge restraint , Joint Adhesive
39. Respondent did not complete this question.
40. The contractors do not want to spend money for heaters, attachments and the like.

Q14) In your experience, please rate the performance of the specific construction method based on visual, permeability, or density observation.

Q15) In your opinion, describe why these construction methods are performing better than others?

1. Respondent did not complete this question.
2. Respondent did not complete this question.
3. Respondent did not complete this question.
4. More overlapping on wedge
5. Respondent did not complete this question.
6. I think some of the other methods have higher density at the joint and less cracking
7. Respondent did not complete this question.
8. I like sloped edge device that semi compacts the outer edge and allows for better edge compaction. Mill and fill works well because there is less handwork. Handwork never turns out well. I would like to see turn lanes and wedges be fixed or go away due to handwork.

9. Mill and fill is best, but not practical. Paper Butt joints have worked well when properly constructed.
10. Respondent did not complete this question.
11. Unfortunately, we rarely employ some of the methods described above in SCDOT practices
12. Joint adhesive is something extra to help establish the bond between the two mats. We have not tried some of the others so I am not familiar with them.
13. We don't deal with freezing temperatures in our area, so butt joints seem to perform fine. Mill & Fill operations work well when the opportunity presents itself. Echelon paving requires multiple lane jobs and not practical for DOT work, ok on airport projects with no live traffic. Heaters, adhesives, etc. are costly and slows the operations down, thus raising the cost per mile of resurfacing.
14. Respondent did not complete this question.
15. I would expect echelon paving would work the best since you can have hot uncompacted asphalt tie to hot uncompacted asphalt. The joint should seal together better. With Sequential Mill and Fill, you have a hard compacted edge to compact against, which improves the compaction of the new joint and allows better packing.
16. Respondent did not complete this question.
17. Provides the best compaction and overall joint performance
18. Taking more time and effort needs to be done at the joints. Laydown crew experience is becoming less every year, we need to make a change. The layout prior to paving is the single most important item that is overlooked.
19. N/A represents I've never seen this done in practice...Joint Adhesive is usually only a normal "Tack Coat" being applied and not some special adhesive product.
20. Respondent did not complete this question.
21. Respondent did not complete this question.
22. Respondent did not complete this question.
23. They are just better construction practices
24. Sequential Mill and Fill is the best method in my opinion.
25. Respondent did not complete this question.
26. This is just what I am familiar with. I dont think the methods are the major component. I would think proper installation is the key regardless of method.
27. Respondent did not complete this question.
28. Respondent did not complete this question.
29. Confined edge gets compacted. No loose material to pave next to on the next day.
30. Respondent did not complete this question.
31. Respondent did not complete this question.
32. Have not encountered N/A responses
33. Respondent did not complete this question.
34. Echelon paving greatly reduces a joint because the asphalt is being pulled in both lanes while it is still hot.

35. The items listed as above average have been observed and have been observed to successful. The joint heater method has only been used as a corrective measure when the amount of asphalt to be corrected has been minimal (but not preferred).
36. Respondent did not complete this question.
37. We have never used any of the above.
38. apply additional tack at the joint face using a wand or angled spray bar to assist with cohesion at the joint. tack few inches past the full paving width to ensure edge will have minimum movement in the compaction process.
39. Respondent did not complete this question.
40. Joint adhesive adds add'l bonding. I would like to see instead of a wedge a step down.

Q16) In your opinion, what are the most important factors to constructing a quality longitudinal joint in asphalt pavements?

1. Hot Joint.
2. Respondent did not complete this question.
3. Respondent did not complete this question.
4. Tack and rolling it hot.
5. Clean joint, proper tack and proper compaction with rollers.
6. Straight lines, proper tack, proper overlap with enough material, if pinching make sure material is compressed toward joint, lute correctly, all rollers compacting at joint
7. Timing of the roller to keep the proper amount of heat in the asphalt at time of compaction; do not over-roll; ...all refer to methods of compaction versus materials...
8. Clean underlying layer, proper tack coat, capable roller operator.
9. Insuring hot mix is placed against the cold joint and rolled to eliminate as many voids as possible. Also, it MUST be a CLEAN cold joint that you are working against!
10. Temperature, straightness, compaction effort.
11. Ensuring that there is an overlap of material from adjacent lanes to ensure the asphalt is "locked" in a uniform layer. In addition, avoid continual lute movement to shove "cold" material back into or shoveled across the mat. Only lute as necessary.
12. Proper compaction of the joint and proper matching of the cold edge.
13. The screed man controls matching a consistent joint, use of electronic joint matchers set properly prevent the use of luting, etc. Having the roller close and not letting the mat cool also seals the joint better than once it has started to lose temperature.
14. Grade, depth and joint sealed.
15. Ensuring the material is fully compacted. The newer practice of eliminating the rubber tire roller and using only steel wheel rollers has contributed to this. The

steel wheel rollers will bridge the joint and not fully compact the asphalt. Rubber tire rollers would knead the asphalt into the joint and provide a better seal.

16. Tack, Rolling, and making sure joint is clean.
17. Pinching the joint, ensuring auger extensions are used when needed, staggering the joints on multiple lifts.
18. Proper layout, the paver operator having a plain view -sight of the paint or string line to pave in a straight line. This is difficult at night, but lasers and lighting do play a big part.
19. A very experienced roller operator who understands what makes a good joint and a foreman and inspector that checks to make sure!
20. Respondent did not complete this question.
21. Staggering joints and roller operators.
22. Achieving the optimum density.
23. Tack coat and compact at the right temperature. Stop luting the mix away from the joint and roll the joint on first pass. Then, go to other side and roll back towards the joint, and roll the joint as many times as the roller pattern says.
24. Paver straightness, compaction efforts, and time.
25. Respondent did not complete this question.
26. The edge needs to be straight, clean and leveled. Then, the asphalt should be overlapped by the next pass a few inches with excess material and luted back toward the area to be rolled.
27. Consolidation and compaction.
28. Maintain clean straight joints
29. See other #29 responses.
30. A joint needs to have a good alignment and be straight.
31. Perform proper joint alignment and roll to meet the temperature requirements, maintaining non-segregation of mat.
32. Rolling pattern
33. Respondent did not complete this question.
34. Compact and heat the joint, and apply adhesive
35. Ensure adequate overlapping and do not lute/rake excess material back into the joint.
36. The most important factor to constructing a quality longitudinal joint in asphalt pavements is the prep work prior to paving.
37. Insure a good straight line to match and require proper tack coat and compaction.
38. Clean the edge and tack the edges properly. Add additional tack. Allow more time to tack and properly cure. Ensure the gate is extended far enough to allow for approximately 1.0 to 1.5 " of overlap over the joint. Properly lute the joint, only if necessary. Ensure the height of the loose lift is higher than the adjacent lift so the final compacted height will be slightly higher than the previously constructed mat. Maintain a uniform head of material at the auger points to ensure enough material is present consistently at the joint throughout the paving operation. Ensure the first pass of the breakdown roller is approximately 6" away from the joint to ensure material is being compressed towards the joint rather than overlapping the

joint for the remaining passes with the rollers. Make sure all of the rollers are compacting at the joint, not just the breakdown roller. Overhang the roller by approximately 6" while compacting edges.

39. Pay attention to the detail.
40. A little extra material rolled into the joint.

Q17) What recommendations do you have for how to improve the quality of longitudinal joints in asphalt pavements?

1. Quality of construction practices utilized in the field and not production.
2. Respondent did not complete this question.
3. Respondent did not complete this question.
4. Wedge.
5. When milling the second days pull mill into the freshly paved adjacent lane to mill away old longitudinal lane. This eliminates the possibility of there being old asphalt interface remaining between the lanes.
6. Test different methods and evaluate.
7. Train and require re-certification for roller operators, and more studies to prove/disprove the effectiveness of different methods of joining.
8. Hot pinch with overlays and institute more mill & fill instead of overlaying everything to assist with edge compaction. Also creates more RAP to potentially lower asphalt costs. Come up with another alternative to crack seal for the lower state and Pee Dee that won't swell when overlay HMA applied. Possibly use the WMA for overlaying existing crack sealed roads.
9. Establish a rolling pattern with proven results and ensure the cold joint is clean and properly tacked.
10. The contractor and inspector should discuss beforehand to ensure a good result.
11. Require overlap of longitudinal joints in the specification. Also, see above #11 for recommendations.
12. Try to get the paving crews to use best practices of compaction and matching. If this is done correctly, the issues of joint deterioration in this state will be helped. Maybe, it will not be fixed, but it will help solve many of the problems.
13. There is not a specification that can be written, but a best practices guide for all to follow should help. Every road that is resurfaced brings forth unique different challenges.
14. Training.
15. I would recommend requiring the use of a rubber tire roller back into the specifications. I have been seeing a lot of issues with compaction in pavements where contractors are beating the material to death with vibratory steel wheels in recent years. The excessive compaction is breaking the asphalt back down instead of compacting it while trying to achieve required density. They always think hitting the asphalt pavement with stronger load is the better way of compaction. The part of reasons is a lack of training of roller operators, a lack of supervision, and understanding by QC personnel in roller compaction settings. The perception

of the contractor QC field inspectors is that they have to shoot a nuclear gauge density or take a core, and they don't need to oversee the entire paving operation for quality. A rubber tire will not damage the structure of the asphalt and break it back down. After the rubber tire compaction, the surface pickup of fines need to be addressed and remove the roller marks.

16. Respondent did not complete this question.
17. Specific contract requirements in how longitudinal joints should be done.
18. Wedge maker in the paver and joint adhesives are likely the easiest way to implement and make a difference.
19. Interstate paving joints appear to be the problem areas where I've seen having issues. So, a compaction specification for all interstate paving should be considered or a performance specification that holds the contractor accountable for a certain number of years beyond completion.
20. Over the past few years, in my experience, longitudinal joints have improved dramatically. However, if I had to give a recommendation, it would be to educate the QC and roller operators on the importance of their actions.
21. Proper looting and rolling should be done.
22. Respondent did not complete this question.
23. See above #23. Also, the roller operators must be required by their company to roll correctly. Number of passes on the joint. Roll towards the joint not away from it.
24. Plan the operations ahead of time to ensure adequate sequence of operation.
25. Respondent did not complete this question.
26. I feel proper installation with a good lute man and technique will do you good.
27. Enforce uniformity from contractors to contractors.
28. Maintain clean straight joints.
29. Same as all my other answers in #29. Unconfined loose material at each lift needs to be addressed.
30. Require the use of a physical string line by specification.
31. Alignment training for paver operators and training for proper compaction methods for roller operators.
32. Increase inspection emphasis.
33. Respondent did not complete this question.
34. Restrict the use of certain methods that prove to provide a less than adequate product. Install certain methods in the contracts for resurfacing projects.
35. Ensure that longitudinal joint practices such as overlapping are introduced into the specifications other than just "best practices."
36. Take the additional time to prepare the longitudinal joints.
37. Ensure paving contractor and inspectors adhere to the comments above (#37 responses).
38. Clean the joint area to ensure excessively loose material is removed prior to paving. Tack few inches pass the full paving width. Apply additional tack at the joint face. Allow time for tack to properly cure before placing the layer of asphalt. This step is especially a critical near unrestrained edges.

39. Matching lanes with straight joints is performed easier than matching a lane that wasn't pulled straight.
40. Cold rolled would probably be the best of the three mentioned on earlier page.

Appendix B

Table B.1 Field Density Comparison Results

Projects	Field Density			
	J/H	Average	SD	CV (%)
SC8	0.99	0.99	0.01	0.67
	1.00			
	0.99			
US178	0.97	0.97	.	.
I77	1.02	1.01	0.01	0.93
	1.00			
	1.01			
S39-57	0.99	0.99	0.00	0.38
	0.99			
	1.00			
SC203	1.01	1.00	0.01	0.86
	0.99			
	1.00			
	1.00			
SC 11	1.01	1.01	0.01	0.82
	1.02			
	1.00			
SC254	1.00	0.99	0.01	1.19
	0.98			
	0.99			
US25	0.96	0.97	0.01	1.31
	0.98			
	0.98			
US25(2)	1.00	1.00	0.01	0.86
	1.00			
	0.99			

Table B.2 Field Infiltration Comparison Results

Projects	Field Infiltration			
	J/H	Average	SD	CV (%)
SC8	1.88	5.62	6.61	118
	13.24			
	1.73			
US178	.	.	.	.
I77	.	.	.	.
	.			
	.			
S39-57	2.39	1.60	0.82	51
	1.67			
	0.75			
SC203	0.90	1.75	1.00	57
	2.86			
	1.50			
	.			
SC 11	0.39	0.38	0.02	6
	0.35			
	0.39			
SC254	0.52	4.01	5.40	135
	10.23			
	1.28			
US25	3.75	3.66	1.45	39
	2.18			
	5.06			
US25(2)	0.70	2.41	2.65	110
	1.07			
	5.46			

Table B.3 Lab Density Comparison Results

Projects	Lab Density			
	J/H	Average	SD	CV (%)
SC8	0.94	0.93	0.01	1.22
	0.91			
	0.93			
US178	0.88	0.88	.	.
I77	0.98	0.98	.	.
	.			
	.			
S39-57	0.88	0.89	0.02	1.85
	0.89			
	0.91			
SC203	0.95	0.95	0.01	0.73
	0.94			
	0.94			
	0.95			
SC 11	0.96	0.96	0.00	0.47
	0.96			
	0.96			
SC254	0.97	0.97	0.03	3.25
	0.93			
	1.00			
US25	0.94	0.94	0.01	1.58
	0.95			
	0.92			
US25(2)	0.95	0.95	0.01	0.78
	0.95			
	0.94			

Table B.4 Air Void Comparison Results

Projects	Air Void			
	J/H	Average	SD	CV (%)
SC8	1.66	1.93	0.28	14.3
	2.21			
	1.93			
US178	2.79	2.79	.	.
I77	1.18	1.18	.	.
	.			
	.			
S39-57	2.57	2.32	0.30	13.0
	2.39			
	1.99			
SC203	1.44	1.60	0.14	9.7
	1.76			
	1.65			
	1.55			
SC 11	1.46	1.52	0.05	3.7
	1.54			
	1.56			
SC254	1.34	1.53	0.59	43.9
	2.18			
	1.05			
US25	1.94	1.95	0.25	12.9
	1.71			
	2.21			
US25(2)	1.67	1.80	0.22	13.4
	1.68			
	2.06			

Table B.5 Lab Permeability Result

Projects	Lab Permeability			
	J/H	Average	SD	CV (%)
SC8	52	137	74	54
	179			
	180			
US178	64066	64066	.	.
I77	5	.	.	.
	.			
	.			
S39-57	85	159	175	110
	359			
	33			
SC203	17	67	45	67
	125			
	66			
	59			
SC 11	4	34	35	103
	72			
	25			
SC254	3	21	33	157
	60			
	1			
US25	99	45	49	111
	2			
	34			
US25(2)	18	97	133	138
	22			
	250			

Table B.6 Indirect Tension Strength Comparison Results

Projects	Indirect Tension Strength			
	J/H	Average	SD	CV (%)
SC8	0.35	0.52	0.18	36
	0.48			
	0.72			
US178	0.25	0.25	.	.
I77	0.34	0.34	.	.
	.			
	.			
S39-57	0.12	0.20	0.11	54
	0.16			
	0.33			
SC203	.	0.56	.	.
	.			
	.			
	0.56			
SC 11	0.64	0.54	0.13	25
	0.39			
	0.59			
SC254	0.76	0.67	0.09	14
	0.58			
	0.67			
US25	0.45	0.52	0.06	12
	0.52			
	0.58			
US25(2)	0.55	0.56	0.05	8
	0.61			
	0.53			

Table B.7 Half Core Density Comparison Results

Projects	Half Core Density			
	J/H	Average	SD	CV (%)
SC8	1.02	1.00	0.03	3.46
	1.02			
	0.96			
US178	0.98	0.98	.	.
I77	0.96	0.96	.	.
	.			
	.			
S39-57	1.00	0.98	0.02	1.95
	0.96			
	0.98			
SC203	.	0.95	0.01	1.48
	0.94			
	.			
	0.96			
SC 11	1.00	1.00	0.01	0.92
	0.99			
	1.00			
SC254	1.02	1.02	0.01	1.44
	1.03			
	1.00			
US25	0.96	0.98	0.02	2.07
	0.99			
	1.00			
US25(2)	0.99	0.98	0.01	0.54
	0.98			
	0.98			

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